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AUGUST 1961

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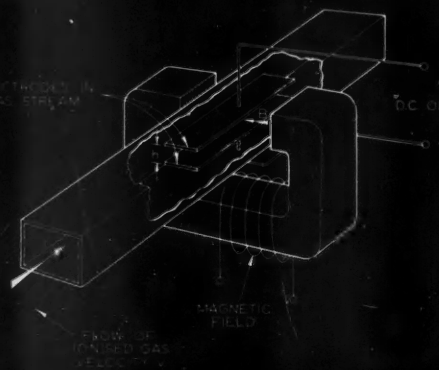

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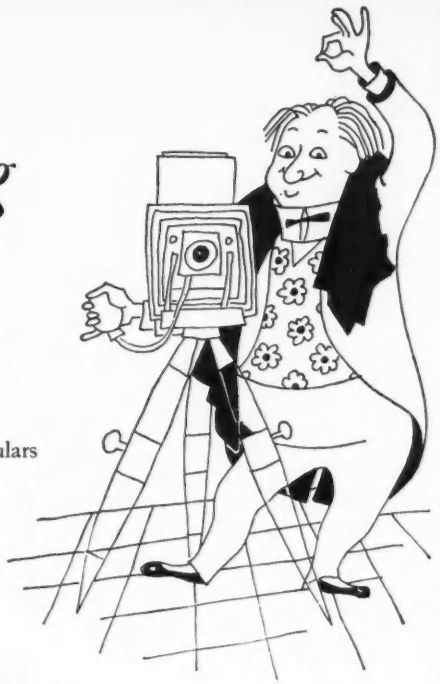

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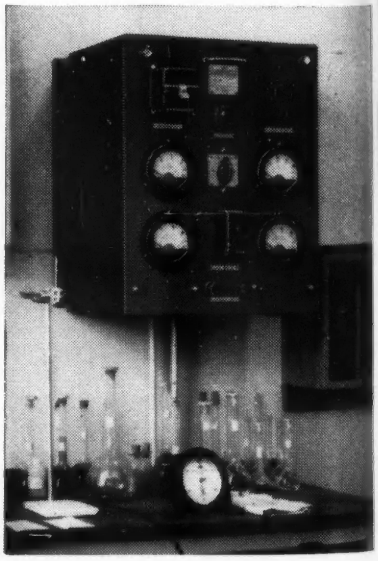

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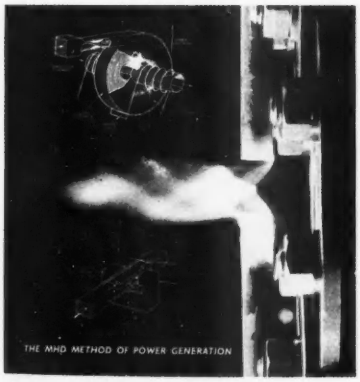

Some of the experimental equipment being used for MHD power generation. See the article on page 326

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THE PROGRESS OF SCIENCE

LARGEST NATURE RESERVE

Last month the Antarctic Treaty, "freezing" political claims to Antarctica for twenty-five years and dedicating the whole area to international scientific endeavour, received final ratification and so officially came into force at a special conference in Canberra, July 10–24. This far-sighted political act will also provide the means for implementing the recommendation of the Special Committee on Antarctic Research (SCAR) now the *de facto* custodian of the region, that the whole area south of latitude 60° be established as a nature reserve.

Sixty degrees south delimits the region for purely Antarctic sea creatures as well for the Antarctic continent's fauna and flora. The area below 60°S takes in all the principal sub-Antarctic islands. The Antarctic continent on its own is as large as the United States and Europe put together. This makes the envisaged Antarctic nature reserve by far the largest such reserve in the world.

In some respects it is also the most interesting. It is the only large region where the balance of nature is still genuinely "natural"—that is, has not already been upset by man. In addition Antarctica possesses the most rigorous climate on the planet and the biological forms that exist there represent the end-points of a highly specialised evolution that cannot be matched elsewhere. The work of the naturalist and biologist in the field has barely begun in terms of what there is to do.

The human population of the continent in summer has stood at 4000 for several years. Unless the principles and objects of conservation can be inculcated and enforced on expedition members, a unique opportunity could be lost beyond recall. Because man and his inventions are unfamiliar and there are few natural predators, Antarctic creatures are extremely trusting. The easy slaughter of fur seals and whales in the past brought both species close to extinction within a few years. They are now protected, but more for maintaining a valuable commercial asset than from the point of view of the biologist and ecologist.

Catastrophes to the balance of nature can occur through thoughtlessness as much as through downright bloodthirstiness or commercial greed. The dangers to the Antarctic offshore environment through the careless emptying of ships' bilges and from pollution by oil fuel is under consideration.

HARNESSING UNDERGROUND HEAT

Nearly thirty years ago when Bernard Shaw visited New Zealand he suggested that the geothermal capacity of North Island, so abundantly evident from its geysers and hot springs, could be harnessed for industrial power. Now a geothermal power station at Wairakei has been delivering 6500 kW of electricity to the national grid for some months. It is the first natural-steam-driven generating plant in the southern hemisphere and its development has proved so satisfactory that up to twenty-seven bores to tap steam down to 3000 ft. and to deliver 70,000 kW of electricity are scheduled.

A second phase of development at the site will increase the power output to 150,000 kW and it is estimated that the natural steam potential in the area can support development of up to 260,000 kW. Once testing and installation are complete —and this is the tricky part of the operation—power from natural steam is the cheapest power source in the world. The cost of all three stages of New Zealand's Wairakei project is estimated at £21 million.

Wairakei is in fact only one small outcrop of the vast thermal region of New Zealand's North Island. The whole region extends across the centre of the island in a huge triangle, whose points are marked by the active volcano Ruapehu to the south, the spa town of Te Aroha in the west and an island offshore that rises blazing out of the Bay of Plenty on the eastern seaboard. The United Kingdom consultants who have been advising the New Zealand government on the development estimate that there are 7390 million British Thermal Units locked up in this triangle waiting to be used.

It is possible that, when this new source of natural power is exploited, the steam may give out when released. Virtually nothing is known of the source of the underground heat, nor of its geophysical cause. At the present state of knowledge the chances are even for steam production from underground to continue unimpaired.

Elephant seals breeding on Macquarie Island. The Australian authorities, backed by public opinion, refused to allow sealers to harvest Macquarie seals again, in 1959.
(Photo by Carrick & Ingham)

NOISE

Noise is a nuisance. It results directly from life in an industrialised community. What can be done about it? This was the subject of a valuable three-day international conference held recently at the National Physical Laboratory, Teddington.

The noise level in Britain has risen to such a pitch that government action is envisaged. The Wilson Committee on The Problem of Noise was set up a year ago and after a further year's work will make recommendations expected to lead to government legislation. This legislation must be based on scientific analysis of problems that are part social, part physical and part psychological. Because the study of noise is an "impure science" it is so complex. Here are points from some of the papers:

plant breeding

Life in both the plant and animal kingdoms is normally a chancy business, with such an element of disorder in its management as to obscure the orderliness that lies within. Primitive folk acknowledged its caprice, and attempted—by a variety of occult means—to turn it to their favour. At the same time they sensed, in a primitive way, its potential for orderliness and sought to gain some control of it. So, for example, they selected seed from what seemed the best of the wild types of crops, and improved their resources of food in this mildly systematic way.

It was not until late in the 19th Century that more systematic improvement of crops was obtained with the introduction of cross-pollination of selected parents; and even then it was practised more as an art than a science, for nothing was known of the hereditary principles involved. Mendel gained the first insight of inheritance and segregation of characters by his studies of the garden pea, but it was the work of Bateson at the John Innes Horticultural Institution—following on Mendel's work—that triggered the transition of plant breeding from an art to a science, and made planned breeding possible.

We in Unilever Research are applying his techniques to a wide and varied programme of plant breeding. In an age of increasingly sophisticated living the demands of our associated food companies for vegetable crops of the highest quality are growing. But quality cannot be considered apart from those agronomic factors which make for good cultivation, i.e. disease resistance, good plant habit, yield, etc. So, at Colworth House, Kovachich and Rowlands are engaged in research into the breeding of vegetable crops to produce types of the right overall quality for an expanding food industry.

UNILEVER RESEARCH

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Dr D. W. Robinson, Head of the Acoustics Department, NPL, gave some figures on *noise energy*.

Noise viewed from the physical standpoint is just a form of energy, but a little goes a long way. Someone calculated that all the noise made by a Cup Final crowd would scarcely boil a kettle. A jet engine is one of the more efficient sources of noise, yet it produces only a few horsepower—perhaps 20—compared with the power of the engine which may be 200,000 h.p. or more. . . .

To reduce the noise of a jet engine to a comfortable level we should need to reduce the conversion of kinetic energy into sound from 1 part in 10,000 to somewhere around 1 part in 1 million; to reduce it to inaudibility we should have to go to 1 part in 10,000 million. Yet I am convinced that a great deal of noise, especially the noise in factories, is unnecessary noise which it would take no expert to diagnose and remedy.

Dr A. Carpenter, Medical Research Unit, discussed *noise* and *performance*.

Does noise cause mental illness? This is the most nebulous of the health worries relating to noise which preoccupies the public. If noise by itself could produce neurosis symptoms in individuals there would be valid evidence for this connexion. Comparable population groups exposed to noise and not exposed to noise should show divergent neurosis-incidence. U.S. sailors serving on aircraft carriers (one of the noisiest situations known) have been compared with other control groups of sailors, and no difference in neurosis incidence appeared.

Does noise cause physical illness? The idea here is that noise is a physical stress which in some way makes increased demands on people and therefore induces stress symptoms. Only two have been observed. (1) There is an increase in muscular tension, in heart- and breathing-rates, and electrical skin-resistance changes, at the onset of an unfamiliar noise. The effects are transient. (2) Persistent noise appears to cause contraction of the arterioles of the hands (and perhaps feet) producing a reduction in finger volume, paleness and various paraesthesials. Effects are small and inconstant but they are said to be permanent. "It is possible that among people who work in very noisy places, there are some in whom this effect produces at least inconvenience or discomfort.

Noise does affect the temper. Much work has been done on what makes a noise annoying, as follows:

(1) Loud sounds are worse than less loud.
(2) High-pitched sounds are worse than lower pitch.
(3) Noises containing discrete tones are worse than noises with a smooth spectrum.
(4) Irregularity, of loudness *or* pitch, is related to annoyance.
(5) Rhythm in sound can have a variable and sometimes extreme irritation value depending largely upon what else the hearer is doing.
(6) All the previous effects can be void *if the noise has meaning for a particular hearer.*

In practice, noise has not been found to impair performance unless it has reached the 90 db level. Above 90 db, in tasks which demand continuous attention, noise produces an increase in errors and failures in spotting unexpected events. Those who are trying hardest are most likely to be upset by noise.

FRONTIER WORK IN ATOMIC ENERGY

The net operating budget of the Atomic Energy Research Establishment, Harwell, now stands at £15 million a year. Eighty per cent of this goes on project research (such as nuclear power reactors); 20% on fundamental work. Commerce in radioisotopes and the associated technology brings in £1 million a year now.

It is not surprising that AERE is perhaps the most expensively equipped and well-staffed laboratory in the country, with the highest paid staff. We illustrate here some of the frontier work pursued at Harwell in a bewildering variety of fields, as shown in a series of open days this summer.

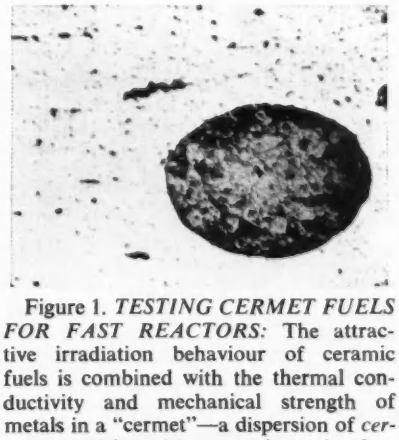


Figure 1. *TESTING CERMET FUELS FOR FAST REACTORS:* The attractive irradiation behaviour of ceramic fuels is combined with the thermal conductivity and mechanical strength of metals in a "cermet"—a dispersion of *ceramic* particles with a *metal* matrix. Cermet, in fact, appears the promising fuel of the coming generation of fast reactors.

Ceramic particles yield their best properties bonded with metal when spherical. For fast reactors the spheroids need to be in powder form. Many stages of preparation of both ceramic and metal have passed before the phase shown in this micrograph is reached. Uranium dioxide and stainless steel powder have been cold compacted at 50 tons/in.^{2} to produce optimum bonding.

A cross-section of a flake of the resulting material is here photographed at a magnification of $\times 215$ to study the effectiveness of the bond. The dark oval is the UO_2 ceramic, the speckled white background, stainless steel. The larger black areas are undesirable; they are formed by air bubbles which retain heat instead of transmitting it as compacted material does.

Figure 2. *OBSERVING HIGHLY RADIOACTIVE PROCESSES:* Much progress has been made in the design of windows for monitoring critical processes in work with radioactive materials. Roughly, the thicker the window the greater the protection. But very thick windows of conventional materials, plastic or glass for instance, produce optical distortion and are very expensive, among other disadvantages. The optical distortion in the feet-thick glass block window of Fig. 2 is well illustrated here. The Remote Handling group at AERE have now developed a liquid window (using zinc bromide) with high protection qualities and low optical distortion. If high temperatures occur in the process being observed the zinc bromide tends to boil, so for most atomic energy applications the windows have an interior face of heat-resistant plastic.

(continued on page 364)

SPACE RESEARCH

ANGELA CROOME

THREE-COUNTRY STUDY OF JUPITER

Radio astronomers at Sydney, in Chile and in Florida are carrying out an intensive co-ordinated research programme during the current three months to try and determine the cause of radio disturbances originating from the planet Jupiter. It is thought that the bursts of radio "noise" that occur from time to time in the vicinity of Jupiter may be due to clouds of electrons from the Sun entering the planet's magnetic field, estimated at ten times the strength of the Earth's field and possibly extending out to 200,000 miles from the planet's surface.

Radio telescopes at the three localities are being trained on the planet almost continuously during this period to define and analyse the effect. If they confirm American observations of "synchroton" radiation—radio emission at a large range of frequencies due to the acceleration of electrons by a strong magnetic field to speeds near the speed of light, as occurs in large nuclear accelerators on Earth—it will indicate that Jupiter is surrounded by intense radiation belts similar to the Van Allen belts recently discovered around the Earth.

The project has been initiated by the Commonwealth Scientific and Industrial Organisation (CSIRO) of Australia and scientists from the three countries involved are working at each other's research centres.

SKYLARKS LIFT U.S. EXPERIMENT

Four British space research *Skylark* rockets will be launched by Australian teams at Woomera later this year for the benefit of U.S. scientists interested in mapping the southern skies in ultraviolet light. The Zimney Corporation of Pasadena, California has the $159,522 contract for providing the instrument packages and spares for the project. The Goddard Space Flight Centre of NASA has designed the experiment; RAE, Farnborough supplies the four British rockets and the Australians who man the Woomera rocket range will supervise the launching, tracking, and data recovery, making this a truly international co-operative exercise.

Ultraviolet astronomy is a new science of great promise. As ultraviolet light from the stars and galaxy cannot penetrate the upper layers of the Earth's atmosphere, this whole range of the spectrum of the firmament and the cosmological information it contains has been blank. It has had to wait for the advent of rocket and satellite skills which alone can lift the ultraviolet telescopes above the filter of the atmosphere.

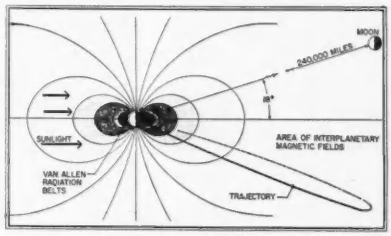
The first results of the first rocket view of the ultraviolet sky were presented at the Moscow IGY conference in 1958 by the pioneer in this field, Dr Herbert Friedman of the U.S. Naval Research Laboratory. Since then the science has had more than its share of bad luck. No ultraviolet satellite has yet gone into orbit to expand and refine the remarkable and puzzling picture then presented. (*See* DISCOVERY, October 1958, vol. 19, No. 10.) All the rocket measurements made so far have been confined to the Northern hemisphere skies so that the stellar picture is incomplete and unbalanced. NASA, with larger funds at its disposal than NRI for pure research has now taken over the large-scale development of this work. It is excellent that negotiations are now complete between the various sponsoring bodies for the ultraviolet study of the Southern skies and that we can expect the launching of the first payload soon.

THE 60-HOUR PROBE: PRELIMINARY REPORT

At 1017 hours EST on March 25, 1961, a *Thor-Delta* rocket launched a NASA satellite intended to gather information on the Earth's magnetic field, on the interplanetary magnetic field and on the way these fields affect and are affected by the streams of electrically-charged particles (plasma) thrown outward by eruptions on the Sun's surface.

The 78-lb. satellite, *Explorer X*, went into a highly elliptical orbit which carried it, during its 60 hours of effective life, out into space almost to the distance at which the Moon orbits, as was intended (see diagram). The "window"—or period during which the probe could be launched—was restricted to 3 hours per day of only 10 days of each month. This was due to the highly specific trajectory requirements, demanding the proper relative position of Earth, Sun, Moon, and payload, for instrumental reasons and so that the probe lay in the right path to detect and measure particles emitted from the Sun and passing beyond the Earth.

The probe carried a newly-developed type of magnetometer never previously tried in spaceflight, the rubidium-vapour magnetometer, a most accurate and sensitive instrument of extreme technical sophistication. Besides "proving" the satellite version of the instrument its readings were expected to give much sharper definition to the magnetic field strength data over that obtained by *Pioneer V* a year before—the only significant material on the subject previously collected (see DISCOVERY, 1960, vol. 21, No. 7, p. 309). In addition, the new instrument made possible measurements of hydromagnetic shock waves coming from the Sun and impinging on the Earth's field.



Trajectory of Explorer X *during the 60 hours of active battery life. Apogee of 145,000 statute miles at the azimuth of 140°–150° from the Sun–Earth direction, was reached 59 hours after launch. Perigee estimated at 100 miles from Earth's surface but by then the radio was silent, as indicated by the broken line of the return trajector.* (*Diagram by courtesy of NASA*)

At this summer's meeting of the American Geophysical Union in Washington a preliminary account of the probe's findings was given. This report was based on "quicklook" data reduction and the detailed analysis is promised for the near future.

The main results announced in the preliminary report are as follows:

1. The interplanetary magnetic field seemed to be more intense than anticipated.
2. Large, sudden changes in the magnetic field—presumably shock-waves—were detected.
3 There were changes in the magnetic field in space which synchronised with the sudden commencement of a magnetic storm on the Earth's surface (in this case, after a class-3 flare had occurred on the Sun).
4. The plasma flux travelled predominantly from the direction of the Sun. (Measurement of the Plasma particles was limited to "low-energy" protons, that is, to those with velocities between 6 and 1000 m.p.s.

MAGNETOHYDRODYNAMIC POWER GENERATION

D. T. SWIFT-HOOK

Magnetohydrodynamic (MHD) power is produced directly by passing a hot conducting gas through a magnetic field. This method of generation offers the prospect of much higher thermal efficiencies than conventional power stations, and developments in rocketry and thermonuclear research have increased the chance of solving the technical problems. But much remains to be done

NEW METHODS FOR GENERATING ELECTRICITY

Modern coal-fired generating stations have been developed to a very considerable degree, particularly during the last decade or so. The position is still improving but it will be very difficult to increase the generation efficiency much beyond 40%. The efficiencies of atomic power stations are much lower and the capital costs much higher; it is only the relative cheapness of nuclear fuel compared with coal (per unit of releasable energy) which allows atomic power to compete.

Looking to the future, further large reductions in the relative cost of power seem likely only if completely new methods of generation can be developed, and a considerable amount of research is being carried on throughout the world on various schemes. Interest has also been stimulated by requirements in the field of space travel for compact systems to generate power for rockets with high specific impulses (in excess of 1000 sec.). Many of these schemes are for direct generation, in which most of the usual stages—whereby fuel is burnt to produce hot gases which boil water to raise steam which drives a steam turbine which drives the dynamo—are by-passed and electricity is produced directly without rotating machinery.

Surprisingly enough most of these methods are not new (as early as 1823 for example, thermo-electricity was capable of higher efficiencies than the existing steam engines) but only with the advent of modern materials and techniques have they begun to look practicable. The immense interest in semi-conductors over the last ten years, for instance, has opened up the

Mr Swift-Hook is in charge of the MHD Generation section in the Research and Development Department of the Central Electricity Generating Board.

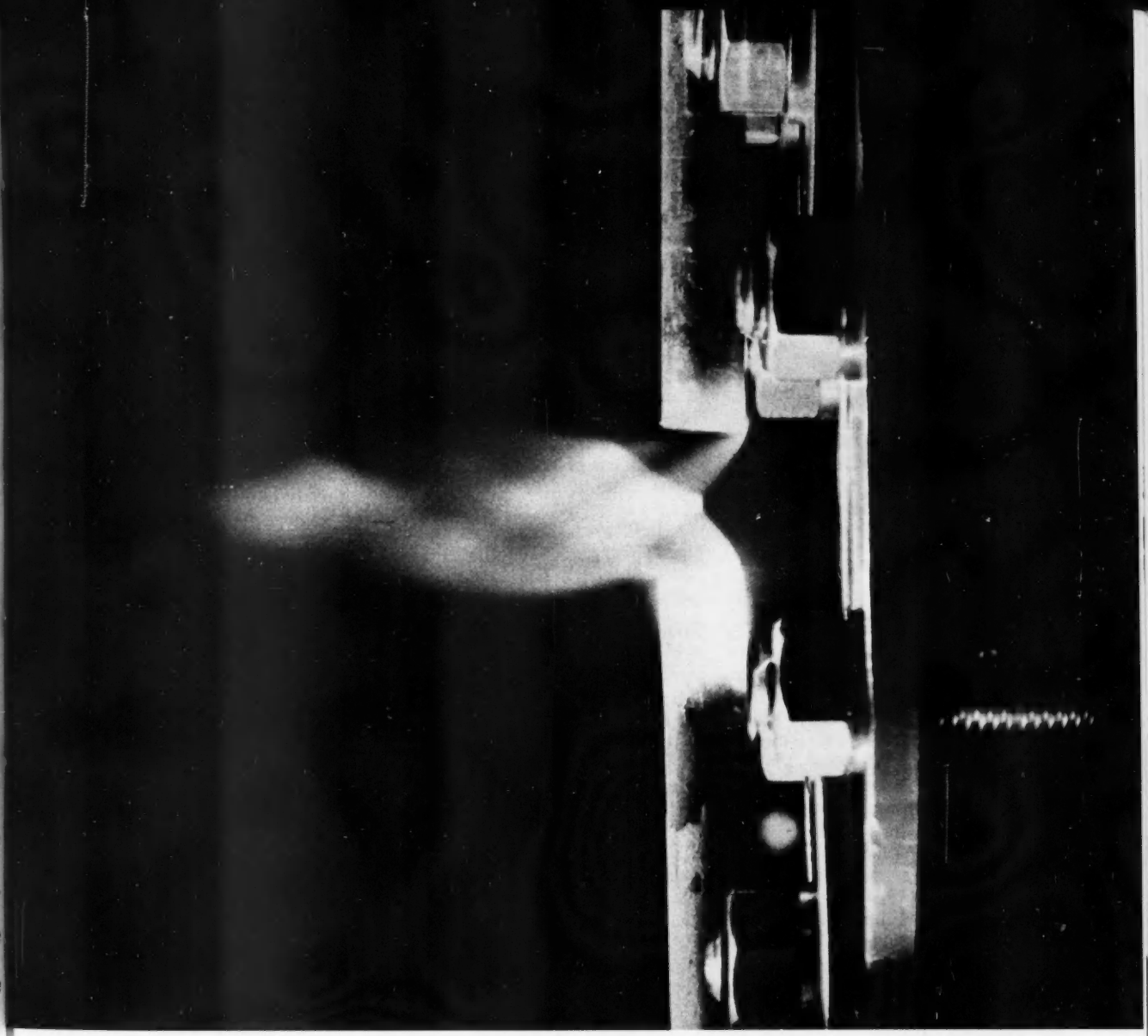


FIG. 1. *Inside an MHD generator. Electrodes in the stream of high-velocity, high-temperature gas become white-hot.*
(Photo by kind permission of the Director, Explosives Research and Development Establishment, Waltham Abbey, Essex)

possibility of new thermoelectric materials with very high efficiencies, and both the thermionic diode and the fuel cell (which is not a heat engine but converts energy directly into electrical energy and is therefore not subject to the same limitations) look promising in the light of modern developments.

Perhaps the most spectacular technological advances in recent years, however, have been in the fields of rocketry and thermonuclear research so that, on the one hand it is commonplace to handle gases at temperatures of 3000°C or more flowing at very high velocities, and on the other, the effects of ionisation and conductivity in gases in the presence of a magnetic field have been extensively studied. These developments have led to renewed interest in the method known as MHD or magneto-hydrodynamic generation (see DISCOVERY, 1960, vol. 21, No. 8, page 326).

THE MHD GENERATOR AS A GAS TURBINE

In this method of direct generation, hot gases produced by burning the fuel (coal, gas, oil, uranium, etc.) are made conducting, for example, by "seeding" with potassium or caesium, and then passed through a magnetic field. As with any conductor moving through a magnetic field, a voltage is produced and electricity may be extracted, for example, by electrodes placed in the hot gas stream. The open circuit voltage generated is given simply by $E=vhB$ (see Fig. 2).

There is a retarding force on the conducting gas due to the current in it produced by the voltage, and the power comes from the work done against this force which can be compared with the force on the blades of a turbine. The MHD generator can in fact be thought of as an "electro-magnetic turbine" with

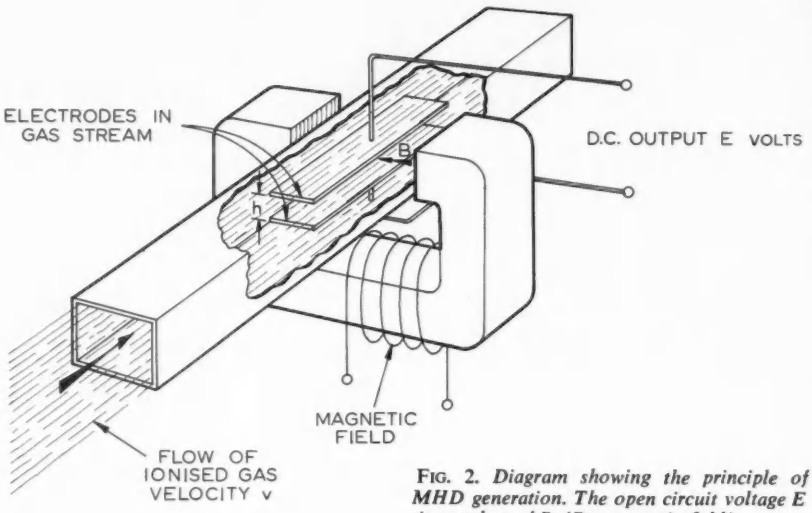


FIG. 2. *Diagram showing the principle of MHD generation. The open circuit voltage E is equal to vhB. (B=magnetic field.)*

"magnetic" blades. These imaginary magnetic blades have the advantages that they can withstand any temperatures and do not suffer from the stresses produced on normal, material blades. Also, the forces on them (although rather weak) are true "body" forces acting all through the gas, and not just on blade surfaces.

The analogy with a turbine can be carried further. When a solid conductor moves through a magnetic field to generate electricity the energy can come only from the mechanical (for example, kinetic) energy of the motion so that the conductor tends to be slowed down, but with a gas it is also possible to obtain work from the potential (that is, pressure) energy by expansion without any change in velocity. Thus two basic types of MHD generator can be distinguished, which correspond to the two basic types of turbine: impulse (in which there is no change in internal energy but only in velocity of the fluid), and reaction (or constant velocity) turbine.

Any practical generator would probably be a combination of these two types. The basic theory follows this resemblance to a turbine even more closely and in the equations the terms for the electromagnetic forces and work directly replace those for mechanical forces and work on the blades in conventional turbine theory.

Thus the MHD generator can be thought of as an advanced type of gas turbine/generator having no rotating parts, and effective blade temperatures at least 1000°C hotter than with present machines—although it must be said immediately that these generators have certainly not reached the stage of being useful to practical engineers as yet.

POWER GENERATION

There are two reasons why a direct generation process may be advantageous for large scale power generation. It may be cheaper to instal since it avoids some of the complexities of the usual systems, and it may be cheaper to operate if it has a higher efficiency. An MHD generator may have both these advantages. The efficiency should be greater because higher temperatures would be used, and because of its simplicity it may have a reasonably low capital cost.

When its temperature has fallen to around 2000°C, the hot gas is of no further use in an MHD generator, since its conductivity is then too low, but it still contains a great deal of heat which must not be wasted. The most obvious way to use this heat is in a conventional generating station so the MHD generator is seen as a thermodynamic "topping" device.

It is difficult to assess the efficiency which may be achievable in an MHD generator. The available Carnot efficiency may be as high as 30% or 40%, but only a fraction of this could be achieved in practice. Nevertheless, since this is achieved in addition to the efficiency of the conventional plant which follows the MHD generators, considerable improvements on present cycles may be possible. It is this possibility of overall cycle efficiencies in excess of 50%, or even 60%, that makes MHD generation look interesting.

With fossil fuels, such as coal or oil, the products of combustion would be the working fluid, and after passing through the MHD generator they would enter the boiler of a conventional steam plant. The question of heat transfer does not arise since the heat is put directly into the working fluid and full advantage may be taken of the available flame temperature, which it is hoped may be as high as 3000°C or more.

The two ways at present envisaged of achieving such temperatures are pre-heating and burning in oxygen instead of air. Pre-heating alone will not give the necessary temperature (with present heat exchangers at least) and the use of pure oxygen would probably be uneconomic, but a combination of the two, using pre-heated enriched air may be the answer. Difficulties with coal (or oil) ash may possibly be avoided by partially or totally gasifying the fuel and burning the resultant gas. In France, the use of natural gas from the Sahara is being considered.

With nuclear (fissile) fuel, a working gas would be heated in the reactor and then passed into the MHD generator, so the nuclear type of device suffers from all the problems associated with heat exchanging at very high temperatures inside a reactor. If these problems can be solved, however (for example, by using some sort of pebble or fluidised bed containing nuclear material), some advantages appear.

A gas such as helium can be chosen for its thermodynamic and non-corrosive properties and, since a closed cycle becomes possible with total recovery, caesium may be used for seeding. Many of the materials problems may then be somewhat less severe. An experiment along these lines is being planned in this country at C. A. Parson's Nuclear Research Centre. The nuclear reactor will be simulated by electrical heaters and the hot helium will be seeded with caesium, passed

through an MHD duct and around a closed cycle.

MHD POWER GENERATED

Although the MHD effect can be demonstrated quite simply with a magnet and a bunsen burner, the first reasonable amounts of MHD power were generated in the laboratory only two years ago by AVCO in the United States. For experimental purposes the stream of hot gas was produced, not by burning a fuel, but by blowing argon through an electric arc, a "plasma jet". Very high temperatures are obtainable in this way. These experiments, and similar ones by General Electric also in the U.S.A., produced kilowatts of electric power for a short time when the argon was seeded with potassium in the form of potassium carbonate. The ducts through which the gases flowed melted or vapourised after only a few seconds.

Other work had already started in the U.S. and in this country, and the next big advance came when Westinghouse (U.S.) reported that they had obtained several kilowatts of MHD power from a generator which burnt oil and which lasted for many minutes. They used a duct made of zirconia (melting point 2700°C) with electrodes of silicon carbide/graphite. The seeding was introduced by dissolving various organic compounds of potassium in the oil. Oxygen was used to give a flame temperature of 2800°C and the output represented 6% of the kinetic energy, or a percent or so of the total energy.

In this country experiments with a shock tube at Imperial College, London, gave one-third of a megawatt for a very short time (a fraction of a millisecond) and the power output was about one-third of the kinetic energy of the gas. Shock tube experiments are also being carried out in the U.K. by Rolls-Royce and various other establishments.

Several organisations such as the Central Electricity Generating Board in this country, and MHD Research Incorporated in the U.S., following the Westinghouse lead, produced varying amounts of MHD power from oil-burning generators, but perhaps the most striking advance was made early this year when AVCO generated 200 kW of MHD power for fractions of a minute from such a generator. They used a wooden duct, the inside of which would be carbonised at the high temperatures involved, but which was cooled by ablation of the surface. (This technique has been used for cooling nose cones of missiles during re-entry into the earth's atmosphere; the heat goes mainly into evaporating material from the surface rather than heating the cone, or duct, itself.) It is expected that this rig will give ½ MW in the near future and there is now no doubt that considerable amounts of power can be generated in this way.

These results are very encouraging; but there are, of course, reservations. All of the experiments have lasted for only a few seconds, or at most, minutes, and the efficiencies have been quite low. Before it can be decided whether MHD generation will ever be economic there are several basic problems which must be solved and a considerable amount of research is being carried out to this end in the U.S., the U.K., and in France.

CONDUCTIVITY

The first problem which must be solved is that of conductivity, since the rate at which electrical power can be extracted from the gases is directly

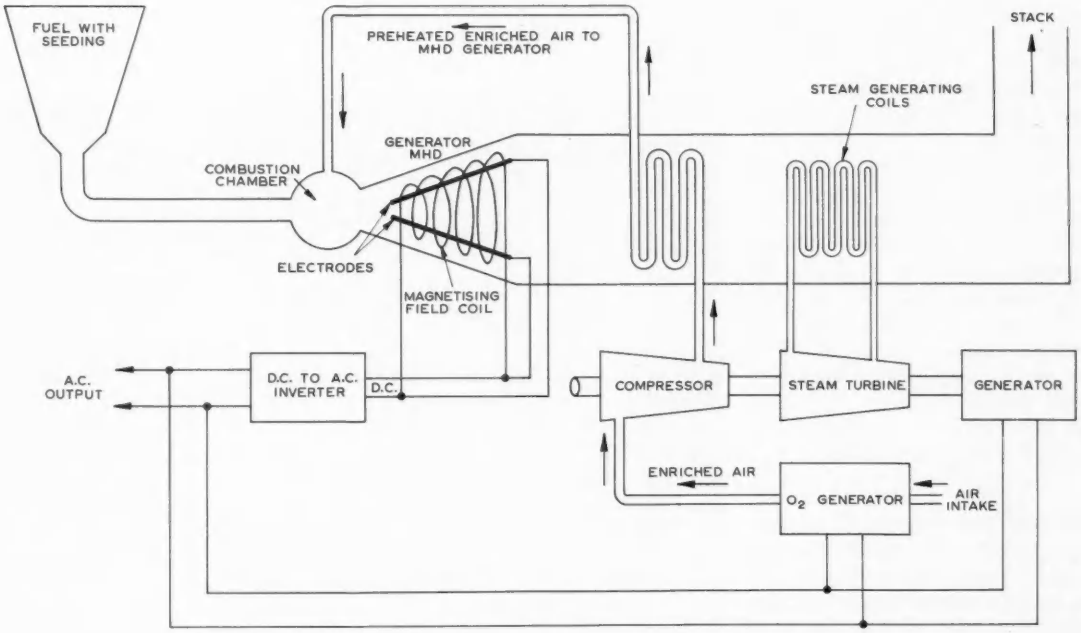


FIG. 3. *Diagram of proposed open cycle MHD plant burning fossil fuel. The MHD generator is used as a thermodynamic "topping" device, and after MHD power has been extracted the hot gases would be passed into a conventional steam (or other) plant.*

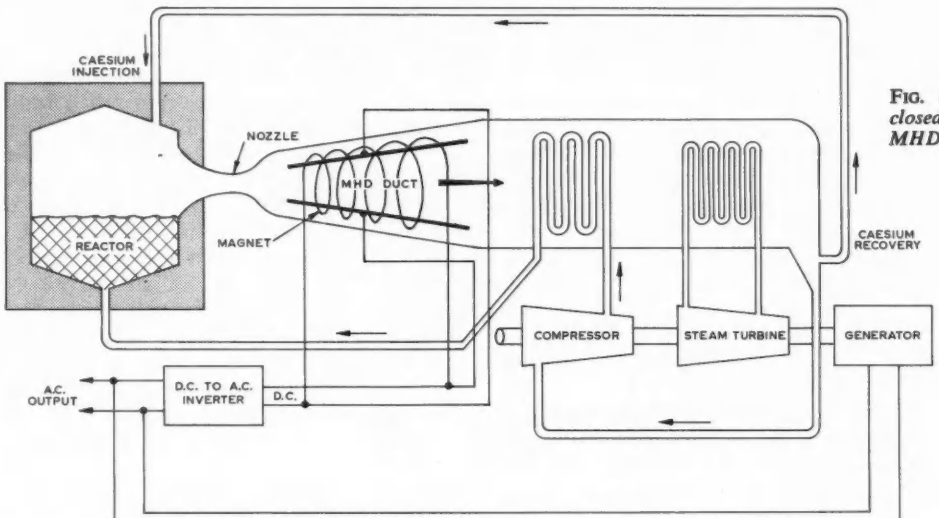


FIG. 4. *Diagram of proposed closed cycle nuclear (fission) MHD plant.*

proportional to the electrical conductivity. Fig. 6 shows the length of duct required for a given conductivity and it can be seen that, if the duct is not to be impractically long, or the magnetic field impractically large, a conductivity of the order 100 $ohm^{-1}m^{-1}$ must be obtained.

It has been known for a long time that hot gases, in a flame for example, are slightly ionised and are therefore electrically conducting. This ionisation is purely thermal and is produced by collisions between hot molecules normally in thermal equilibrium. Conduction is then mainly by means of the free electrons produced. For a highly or fully ionised gas at a very high temperature, such as is found in an electric arc, the sun, or a thermonuclear machine, the conductivity σ_1 is controlled by electron-ion collisions and Spitzer has shown that it varies as:

$$\sigma_1 = a\, T^{3/2}/\log T^{3/2}$$

more or less independently of pressure. For a gas which is only partly or slightly ionised, however, the conductivity is controlled by electron-neutral collisions and is dependent on the degree of ionisation 'x'. This is given by Saha's equation:

$$x = [b\, T^{5/4} \exp(-eV_i/2kT)]/p^{1/2}$$

The factor $1/p^{1/2}$ shows that gases conduct better at low pressures, and V_i is the ionisation potential which gives the collision energy (in electron volts) required to separate an electron-ion pair, that is, to ionise an atom, those atoms having low ionisation potentials being most easily ionised. Thus the conductivity σ_2 of a slightly ionised gas falls very rapidly (more or less exponentially) with decreasing temperature, and more slowly with increasing pressure. If electron collisions with both ions and neutrals are important the resistances due to them add so that the total conductivity σ is given by:

$$1/\sigma = 1/\sigma_1 + 1/\sigma_2$$

The way in which conductivity varies with temperature is shown in Fig. 7. The position of the knee of any curve depends upon the ionisation potential and it is obvious that, for high conductivities at low temperatures, V_i should be as low as possible. The best materials are the alkali metals; caesium (3·9V) is the best of all, but since it is also one of the most expensive, potassium (4·2V) is usually chosen in preference. It is not necessary for the gas to be composed entirely of alkali metal and in practice only a few percent of the "seeding" material is used. Thus Fig. 7 shows the conductivity of air seeded with 1% potassium.

It can be seen that even with seeding and temperatures as high as 3000°C (the brightness temperature of the sun is only 5000°C) the conductivity is not very high (a million or more times less than copper). However, this has proved high enough to enable quite considerable powers to be generated experimentally as already indicated.

EXTRA-THERMAL IONISATION

The need for very high temperatures to produce the necessary conductivity presents many difficulties, and it has been suggested that it might be possible to use ionisation produced non-thermally, for example in a D.C. or R.F. discharge. This technique is certainly valuable experimentally for studying MHD processes in detail without the embarrassingly high temperatures usually required, and in this country both AERE, Harwell, and the CEGB are interested in such experiments using mercury in a closed cycle. The mercury is boiled, ionised, passed through the magnetic field, condensed and re-circulated, all at reasonably low temperatures.

Unfortunately, all known methods of

extra-thermal ionisation appear to need more power just to maintain the ionisation than could be produced by the MHD generator itself, so that such devices do not look economic at present.

HALL EFFECT

The situation is further complicated by various other effects such as the Hall effect. In the presence of a magnetic field the current does not flow in the direction of the electric field but at an angle to it (there is a tensor conductivity). This is only noticeable when the electron collision frequency ν is so low that on average an electron makes an appreciable part of a complete rotation in the magnetic field between collisions.

The conductivity is then reduced by a factor $1/(1+\omega_c^2/\nu^2)$ in the direction of the electric field where ω_c is the frequency at which the electrons rotate (the cyclotron frequency), while the component of current perpendicular to this, which is ω_c/ν times as large, represents an additional ohmic loss. This loss may be very important in practice, particularly when high magnetic fields are used, since values of ω_c/ν greater than 1 are to be expected, but it can be avoided by using segmented electrodes with each pair of electrodes feeding its own load. A component of electric field can then exist along the duct and the current can be strictly transverse while still at the required angle to the electric field.

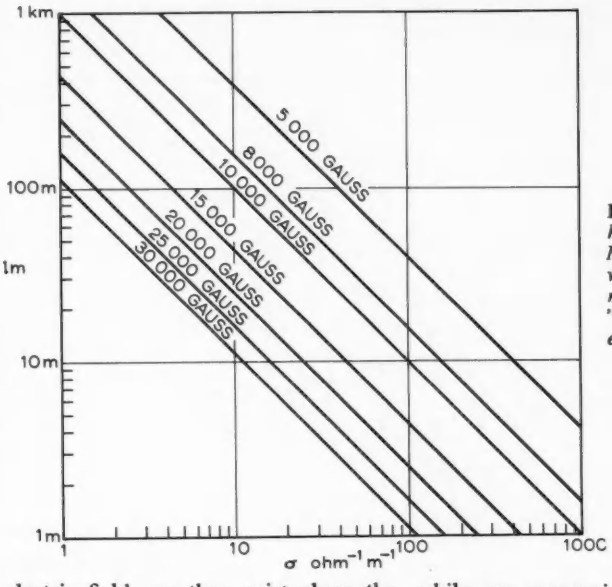


FIG. 6. *Graph showing how the length of an MHD generator varies with conductivity and magnetic field (for an "impulse" type generator).*

HIGH TEMPERATURE PROBLEMS

The most obvious practical difficulties are associated with the high temperatures required for thermal ionisation. The devices which have produced MHD power to date have lasted only a few seconds, or at most minutes, while an economic generator would probably have to last for a period of the order of twenty or thirty years. Materials for the MHD duct will have to withstand very high temperature gases which contain not only caesium or potassium for seeding but possibly also products of combustion.

The most promising materials at present are refractory oxides such as zirconia and thoria, but, apart from being very expensive, these are fluxed by the alkali metals and disappear rapidly downstream as soon as the seeding is introduced. Graphite and the new nitrides and silicides also decompose or burn at these high temperatures, particularly in the presence of potassium or caesium. The only solution at the moment seems to be to water-cool the walls and to accept tremendous heat losses to the water. Since MHD generators will operate in conjuction with steam plant in any case, this may not matter too much.

To take advantage of the electronic conductivity when extracting energy from the gas it is necessary to "complete the circuit" by means of a good electrical "contact" so that electrons can flow freely into the gas. The problem of electrodes therefore presents serious difficulties, since to give good uniform emission they must run hot, and the choice of materials is limited to ones having good electron-emission properties. If hot spots on an otherwise cold surface are used (as in an arc

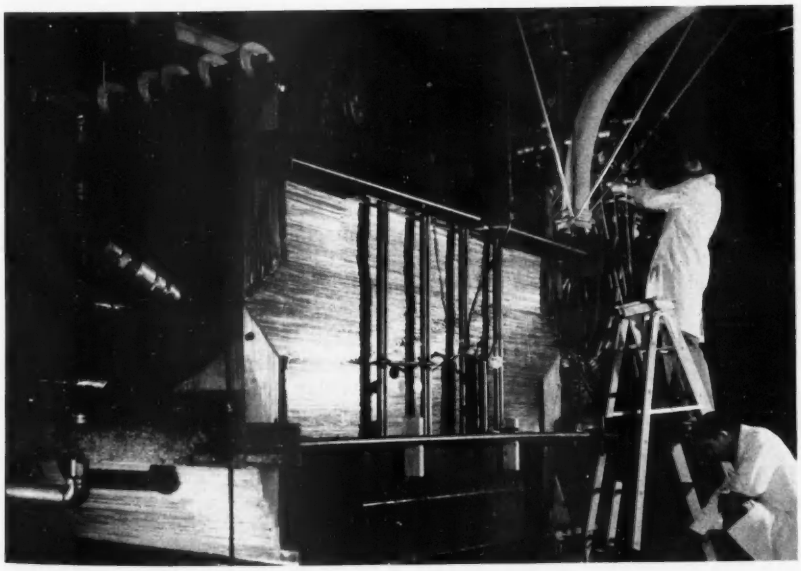


FIG. 5. *Experimental MHD generator built at AVCO-Everett Research Laboratories, U.S.A. This plant has produced 200 kW of MHD power for fractions of a minute.*

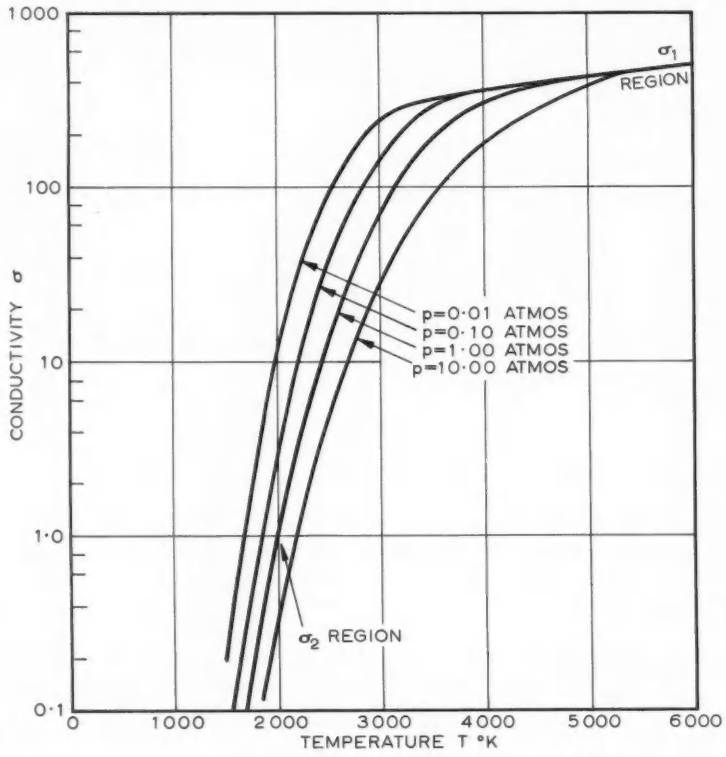


FIG. 7. *Graph showing the variation of conductivity with temperature. At high temperatures σ is more or less independent of pressure, but at low temperatures it is proportional to* $1/\sqrt{p}$ *and falls rapidly with temperatures.*

for example) instabilities may develop in the generator. One suggestion that is being pursued in the U.S. is to use as the cathode a subsidiary discharge, the electrodes of which are out of the main stream.

A.C. GENERATION

Another possible method which avoids the cathode difficulties, and also high temperature problems generally, is to use a pulsed system. If pulses of conducting gas were used instead of a continuous flow there might be three possible advantages. Firstly, the mean temperature which the materials of the duct would have to stand would be much lower while the peak interaction temperature would remain high. Secondly, inductive coupling without electrodes would become feasible so no cathode would be needed, and thirdly, A.C. would be generated instead of D.C. as in the continuous flow case, and expensive D.C. to A.C. conversion equipment would not be necessary.

Several methods have been proposed for varying the conductivity periodically. The CEGB are running small pulse jets (the type of engine used in the German V1 flying-bomb) and resonating flames to pulse the actual combustion and gas flow, while Prof. Thring of Sheffield University (who was one of the first in recent years to revive interest in the possibility of MHD generation on this side of the Atlantic) has suggested that a continuous flow of high velocity, low temperature gas might be slowed down in an MHD generator by means of short sections of high temperature gas introduced periodically into the stream.

Various different methods have also been suggested for extracting the power inductively. For instance, the variation induced in an externally-applied magnetic field by the passage of pulses of conducting gas through it may be picked up on a coil; or self-exciting systems may be designed in which the inductance of a coil is varied periodically by the pulses of conducting gas to produce power by the same principle as is used in parametric amplifiers.

Many of these problems of inductive power extraction also occur with thermonuclear machines (although the conductivities are many orders of magnitude lower, so that magnetic "bottles" cannot be used), and it may be that work in these two fields will eventually converge.

THE VORTEX GENERATOR

The problem of wall friction and heat losses from the gas can in principle be solved by making units so large that the surface to volume ratio is small. Unfortunately, even for a 1000 MW unit, which would be very large indeed, the relative surface losses would still be considerable, as may be seen from the performance of a large rocket motor such as Blue Streak, which is roughly that size. One way of avoiding this difficulty was originally patented by Petersen (in 1918) and has since been "re-invented" independently during the last year or so both in this country and in the U.S.

Imagine the MHD duct wrapped round in a spiral. The inside walls can then be removed to give a vortex generator (Fig. 9) which has the advantage of a long path for the gas flow without a large surface to give wall

Because of the high temperature required, the devices which have produced MHD to date have lasted only a few seconds or minutes, while an economic generator would have to last 20 or 30 years.

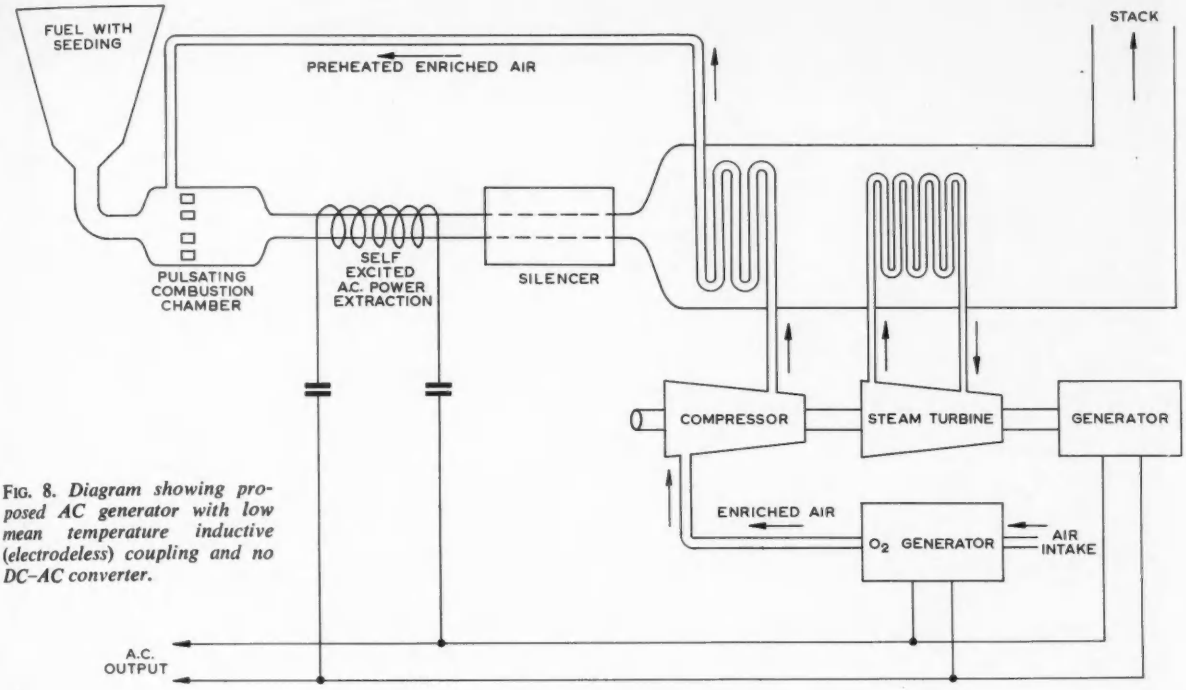


FIG. 8. *Diagram showing proposed AC generator with low mean temperature inductive (electrodeless) coupling and no DC–AC converter.*

friction and heat loss. Experiments with such vortex type generators are being carried out in the U.S. at present.

MAGNETIC FIELD

A large part of the total cost of MHD power will be accounted for by the electro-magnet, not only for the initial capital cost of the installation but also for the power to run it. Because of its compactness the vortex generator is particularly economical on magnetic field and so looks attractive from this point of view also.

A recent development in materials, however, has opened new possibilities for large magnet installations. A material has been discovered (niobium stannide) which will retain its superconductivity even when generating fields as high as 100,000 gauss; most super-conductors lose their properties at much lower fields. This means that a magnet coil of niobium stannide cooled with liquid helium, could produce a field of 100,000 gauss with no dissipation, so that it could be very small and hence, possibly, cheap. The major cost would then be for the liquid helium plant required to keep the coil cool and on a large scale this cost might not be prohibitive.

CONCLUSIONS

While very promising results have already been achieved, it is obvious that many basic physical problems remain to be solved before MHD generation can become economic. The results of experiments which are being carried out at present may show whether many of these problems can be solved, but a great deal more research will be needed before a final answer can be given.

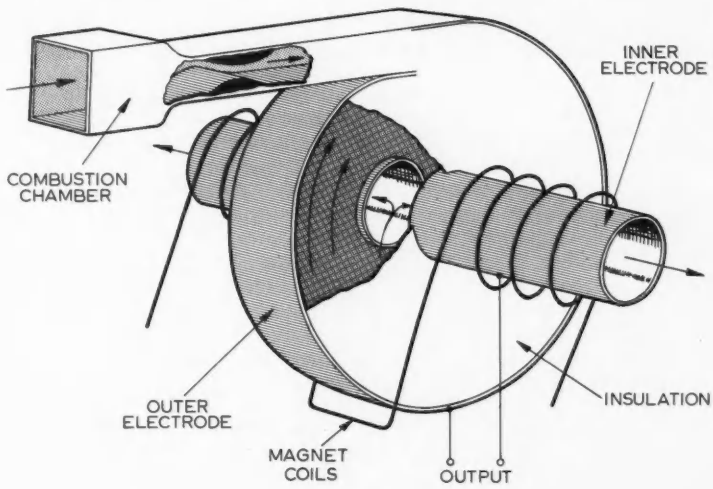


FIG. 9. *Vortex MHD generator. Gas enters tangentially, spirals inwards and leaves axially.*

FIG. 1. *Sunset over Copernicus. This enlargement of the well-known lunar crater is one of those used to produce the topographical map in Fig. 3.*

PROGRESS IN MAPPING THE MOON

ZDENĚK KOPAL

Britain, France, and the U.S. are co-operating in mapping the Moon. Heights of lunar mountains are measured to within ± 10 metres

This is a brief account of the current work on mapping the Moon which Manchester astronomers have been carrying out from the French high-altitude observatory at Pic-du-Midi with the collaboration of the United States Air Force. Since its inception in 1958 our principal aim has been to secure new and more adequate data for three-dimensional topography of the surface of the Moon.

The importance of this needs scarcely any additional emphasis. To the astronomer, the surface of the Moon may give some indication of internal stress and thermal processes. It is also the "impact counter" of external events, which our satellite must have undergone since its formation. To the astronaut, it represents again a territory through which he may have to thread his way in the relatively near future.

In order to meet the anticipated needs for lunar maps in the future, the Department of Astronomy at the University of Manchester, with financial support from the U.S. Air Force, embarked late in 1958 on an extended programme of lunar cinematography —aiming to record sunrise and sunset phenomena over all parts of the lunar surface—with the aid of the 24-in. refractor of 18 metres focal length, at the Observatoire du Pic-du-Midi in the French Pyrenees (Fig. 2). This observatory is situated at an altitude of 9400 ft. and is renowned for the steadiness of the atmosphere above its site which permits the observation of very small details. We are very grateful to Dr Jean Rösch, Director of the Observatory, for allowing us the continual use of these facilities.

In order to secure the actual observations, a K-22 aerial photographic camera has been mounted in prime focus of the telescope (Fig. 6). This camera can accommodate in its magazine more than 100 yards of 9-in. film, which is wound up and exposed automatically (with exposures ranging from one twenty-fifth to a few tenths of a second) about three times per minute at the moments of steady images. A copy of such a photograph is shown on the accompanying Fig. 5 (the image of the watch in its lower right-hand corner indicates the date and time of the exposure).

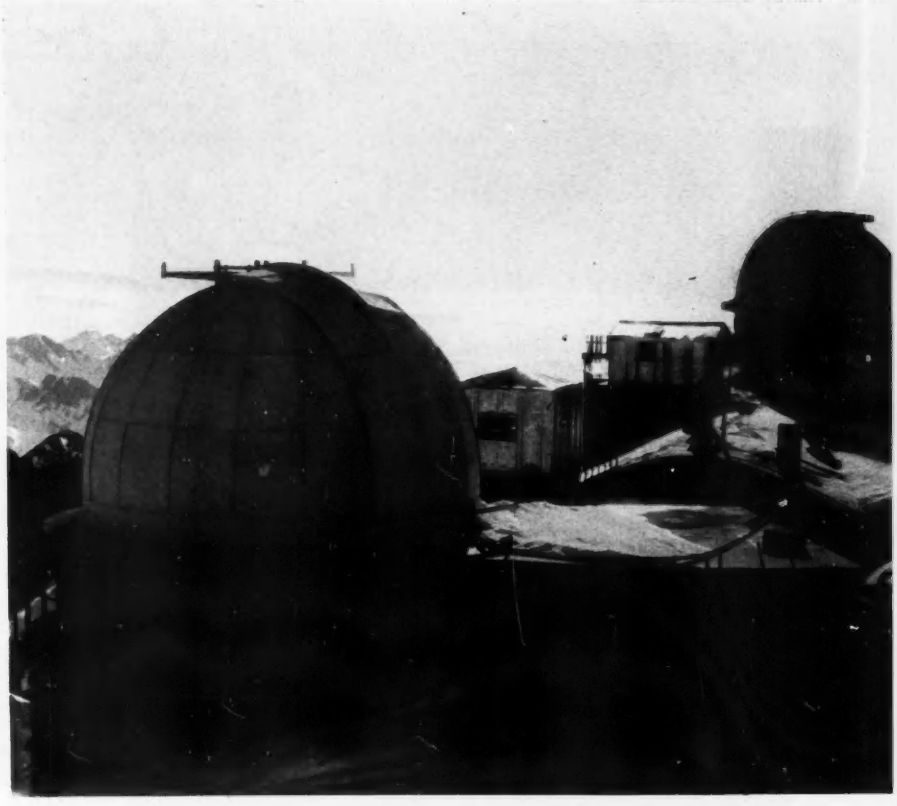
Since the start of systematic lunar photography early in 1959, almost 25,000 negatives have already been taken (several hundred during long clear nights reveal the progression of the shadows at the time of sunrise or sunset on the Moon) by members of our observing team on the Pic. This team includes both Britons and Frenchmen, and operates under the supervision of Mr T. W. Rackham of our Manchester staff (Fig. 4).

Such large quantities of 9-in. films cannot be conveniently processed on the Pic. They are therefore forwarded to the U.S. Air Base at Dreux (France) from where they are taken by air to the U.S. Aeronautical Chart and Information Center at St Louis for processing and measurement.

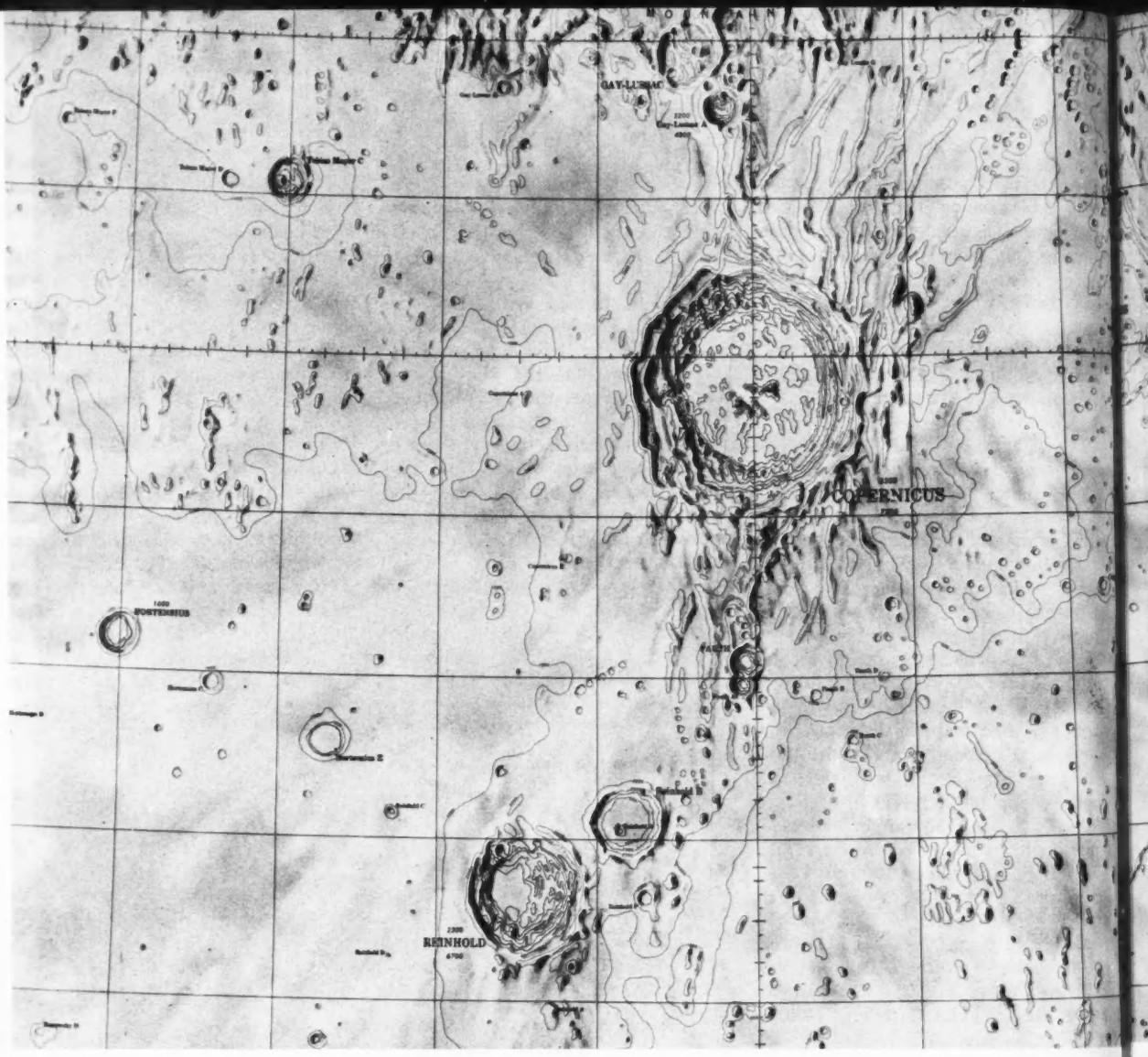
As already mentioned, the principal aim of this work has been to provide new basic information on topographic features of the lunar surface. At the start of our programme, it was planned to construct our charts at Manchester; but subsequent developments have shown that to cope with such a task would be impracticable. We have, therefore, gladly concluded arrangements with the Aero Chart and Information Center of U.S. Air Force and since early 1960 all map work has been transferred across the Atlantic.

With regard to the measurement of the data, micro-densitometric tracings, with the aid of such instruments as shown on the accompanying Fig. 4, must first be secured of all negatives

FIG. 2. *The Pic-du-Midi Observatory in the Pyrenees, 9400 ft. above sea-level, where the Manchester astronomers are photographing the Moon.*



Zdeněk Kopal is Professor of Astronomy at Manchester University.



for accurate determination of the borderlines between sunlit and dark portions of the lunar surface. Results of such measurements can then be interpreted by computer.

The accuracy of our photographs is such that positions on the lunar surface can be measured within errors of the order of one minute of arc in selenographic latitude or longitude (that is, rather less than one kilometre on the actual lunar surface); while the relative heights of lunar mountains can be deduced from the length of the shadows cast on the surrounding landscape within errors of less than ± 10 metres near the centre of the apparent lunar disk—and this at a distance which never becomes less than 356,000 kms.!

All such information is then transferred to the maps of the lunar surface drawn on the scale of 1 : 1,000,000 which are being prepared by ACIC. On this scale, the visible face of the Moon is to be divided into sixty-nine parts, of which about one-tenth have already been dealt with to date. To appreciate the transition from direct photographs to the charts, compare Figs.. 1 and 3. Fig. 1 represents one of our enlarged frames of photographs of a sunset over the well-known lunar crater Copernicus and the Carpathian mountains; while Fig. 3 reproduces a preliminary version of the ACIC map of the same area, containing information from several hundred lunar photographs taken at all angles of illumination.

Similar work on other areas is in progress; it is our sincere hope that the entire undertaking—an experiment in international collaboration between American, British and French scientists and cartographers—will be brought to a successful conclusion before the first man from this earth steps out of his space-ship to face the strange world of the Moon.

FIG. 6. *The K-22 aero-camera used to photograph the Moon, on 9½-in. film. It is in position under the telescope.*

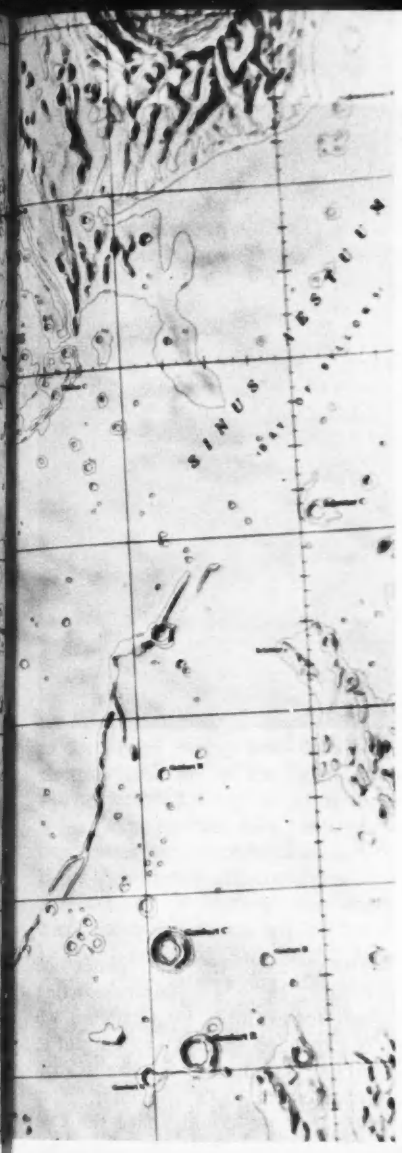
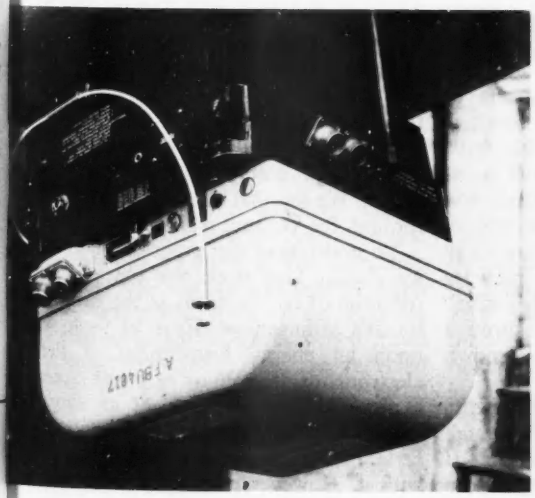
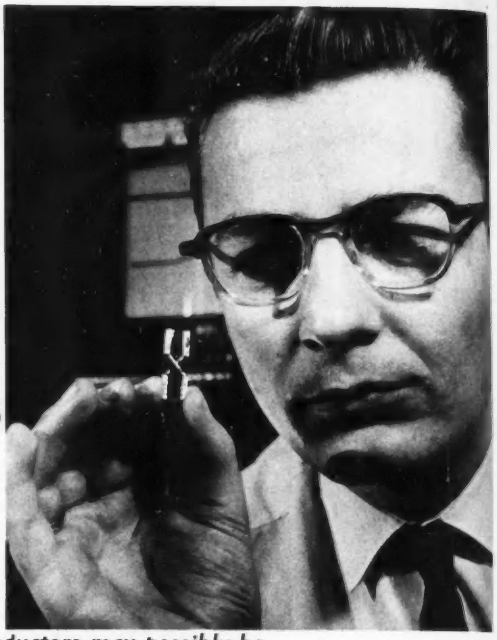


FIG. 3. *A topographical map of part of the Moon, with height contours produced by measuring the length of shadows cast by mountains.*

FIG. 4. *T. W. Rackham, who is in charge of the field force, with a micro-densitometer used for the reduction of lunar shadow photographs.*

FIG. 5. *A typical photograph of the Moon taken on the K-22 camera.*





Dr Giaever holding a laboratory sample used in making his recent discoveries at the General Electric Research Laboratory, Schenectady, New York.

THE SIGNIFICANCE OF TUNNELLING INTO SUPERCONDUCTORS

IVAR GIAEVER

The new characteristics obtained by tunnelling into superconductors may possibly be used in a switch, a triode, a memory unit, a low temperature thermometer or a radiation detector

In simple models an atom resembles our solar system. In the centre is a heavy nucleus corresponding to the sun, and like the planets, the electrons swirl around this centre. To calculate the trajectories of the planets, classical or Newtonian mechanics is used. To calculate the behaviour of electrons, however, classical mechanics often fails, and we have to use quantum mechanics.

Quantum mechanics was developed to explain and predict the behaviour of small particles, and it is an excellent tool. While we often think of the electrons as small balls, quantum mechanics has shown that it is sometimes more advantageous to think of them as waves. For this reason quantum mechanics is often referred to as wave mechanics.

WHERE EXPERIENCE PROVES WRONG

Because we in our everyday experiences are only familiar with the behaviour of relatively large systems in a quantum mechanical sense, we will often be wrong when we try to guess the behaviour of small particles. Tunnelling is a prime example where classical mechanics gives an incorrect answer, and where an intuitive guess would fail.

Consider a man who wants to throw a ball of mass m over a fence of height h. Calling the gravitational acceleration g, the man has to give the ball at least an energy $E \geq h\,mg$ to succeed. This rather obvious result is only true if the ball is large. For balls of atomic dimensions this result is incorrect. Particles of such a small size can penetrate a potential energy barrier,[1] even though this is classically impossible; classically the particles would actually have a "negative" kinetic energy when passing through the barrier. This phenomenon is known as tunnelling.

Experimentally we can easily create such a situation where electrons are the "balls" passing through the barrier.[2] If we connect two parallel metal plates to a battery, and let the plates be separated by a non-conducting medium, for example, by a vacuum, we do not expect to observe any current in the circuit. Commonly we refer to such an arrangement as a capacitor. Now imagine that we could space the two capacitor plates arbitrarily close, say no more than 10–20 atom distances apart. Then a current would be easily observable in the circuit. Since a current is just a flow of electrons around the circuit, we are forced to conclude that the electrons jump from one metal plate to the other across the vacuum region. We say that the electrons tunnel through the vacuum region.

To understand the experiment better we should look upon the energy distribution of the electrons in the capacitor-like arrangement. First let us look upon an energy distribution of the electrons inside a chunk of metal. Such a piece of metal consists of an enormous number of atoms, each with a certain number of electrons associated with it. However, when the atoms are

brought together to form a metal, each metal atom shares a small fraction of its electrons with all the other atoms, and we no longer think of the electrons as swirling around a particular atom.

One result of quantum mechanics is that only a small number of these electrons can have the same energy or the same velocity, if we treat these electrons shared by all atoms as completely free. We may look upon the metal as a low-energy region or box containing all these free electrons roaming around inside the metal.[3]

At absolute zero temperature none of the electrons has enough energy to escape from the metal into the surrounding vacuum. However, because only a small number of the electrons can have the same energy, some free electrons have even at absolute zero a large kinetic energy. We refer to the largest energy possessed by the free electrons in the metal at absolute zero as the Fermi energy and then all the electron levels below the Fermi energy will be occupied. (See Fig. 3.)

In the capacitor-like arrangement two metals are brought close together. If the two metals are connected to the terminals of a battery the absolute energy of the electrons will be different in the two metals, while the kinetic energy distributions are the same if both plates are made of the same material. The vacuum space separating the two metals will appear to the electrons as a potential barrier. Experimentally we know that the electrons pass from one metal to the other, because a direct current flow is observed. If the electrons were small classical particles they could not pass the barrier, for they would have to have negative kinetic energy in its interior.

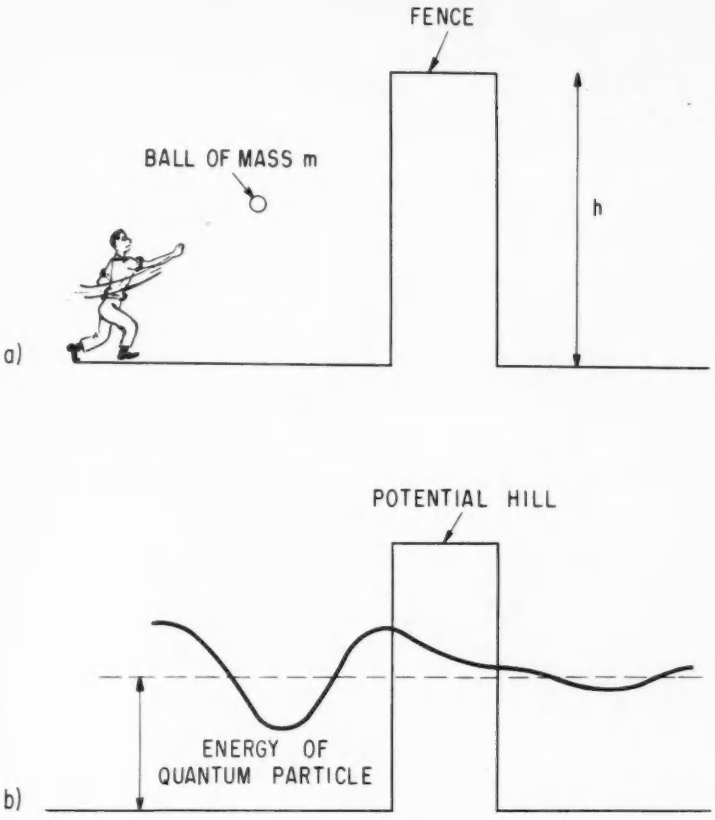


FIG. 1.(a) *When a man tries to throw a ball over a fence, he must give the ball at least an energy* $E \geq h\,mg$ *to succeed.* (b) *If the ball is of atomic dimensions, this is no longer true, as indeed an electron may pass through a potential barrier. We regard the electron as a wave motion, and the amplitude of the wave will decrease going through the barrier. Since the amplitude is an expression for the probability of finding an electron, there is a chance that the electron will pass through.*

THE CONCEPT OF TUNNELLING

The concept of negative kinetic energy does not make much sense, and it is easier to think of the tunnelling process more in the language of quantum mechanics. We may say that the electrons resemble waves which travel through the metal, but are reflected from the interface between the metal and the vacuum. When an electron wave is reflected, the process is not an abrupt one, rather the amplitude of the wave dies out gradually in the vacuum region. Thus if the vacuum layer is very thin as it is in the capacitor experiment, the electron wave may not die down to zero before reaching the other side. Since in quantum mechanical calculations the amplitude of an electron wave at a point is related to the probability of finding an electron there, it means that some of the electrons will pass through the barrier. The small fraction of the electrons that get through are

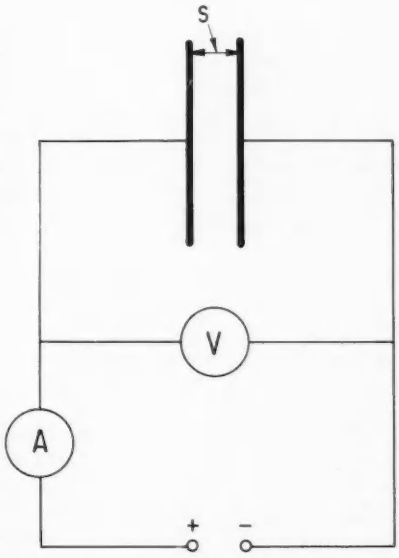


FIG. 2. *A schematic diagram of the tunnelling experiment. If the spacings between the metal plates is made smaller than approximately 100 Å a current will be easily observed.*

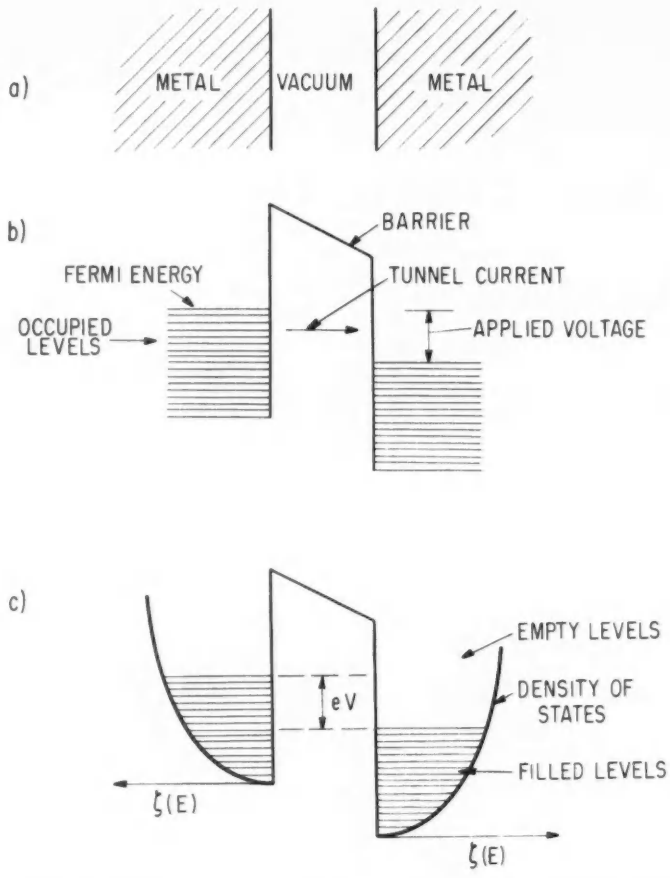


FIG. 3. (a) *The physical arrangement of the capacitor plates.* (b) *An energy diagram of the capacitor plates, showing all the occupied electron levels in the two plates. The vacuum region is pictured as a potential barrier.* (c) *The same energy diagram, but here we have also shown the density of states ρ(E), that is, the number of electrons per unit energy range, as a function of energy. Note that only the electrons inside the range eV [e is the electronic charge, V the applied voltage] on the left can tunnel through the barrier, because only these electrons face empty levels on the right of the barrier.*

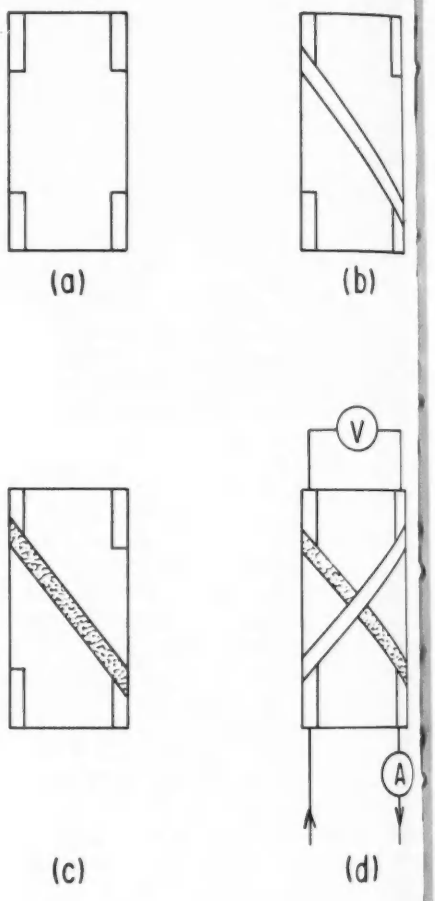


FIG. 4. *Sample preparation.* (a) *Indium solder is smeared on to a clean microscope glass slide to form four contacts.* (b) *An aluminium strip is evaporated across two of the indium contacts.* (c) *The aluminium strip has been oxidised a few minutes in air.* (d) *Lead is evaporated across the aluminium strip, forming a capacitorlike junction. The connexion of voltage and current leads is also shown.*

said to "tunnel" through, and the thinner the layer the larger the fraction of electrons that get through.

The experiment is easily done in the following way. The capacitor-like sample is produced by evaporating a strip of aluminium on to a clean glass slide. Then the aluminium strip is exposed to air for a few minutes causing an oxide layer to grow on the surface of the aluminium. Finally, another metal, such as lead, is evaporated across the first aluminium strip, sandwiching the aluminium oxide between the two metals. Thus we have formed a capacitor-like arrangement. The thickness of the oxide layer may be estimated by measuring the capacitance of the layer and calculating the thickness.

That tunnelling takes place—and not some other conduction process—is shown by the fact that the tunnel current is nearly independent of temperature and decreases exponentially with increasing separation between the metal plates. One may also observe how the current depends upon the applied voltage. For low voltages the current increases proportionally with the voltage, and for higher voltages it increases much faster than the voltage.[4]

WHEN THE METAL BECOMES SUPERCONDUCTING

Below a temperature of 7·2°K, lead becomes superconducting. It loses all electrical resistance and excludes small magnetic fields from the interior of all but the thinnest samples. Larger mag-

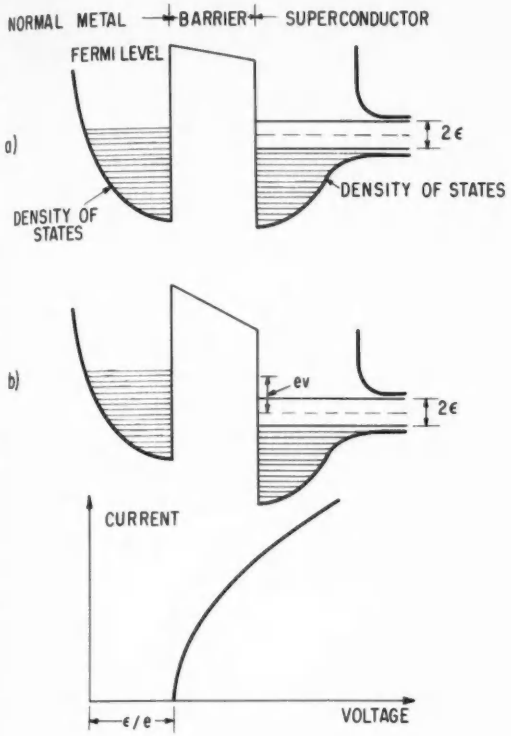


FIG. 5. *Tunnelling between a normal metal and a superconductor. The size of the energy gap, 2ϵ, is exaggerated in comparison to the Fermi level.* (a) *A voltage smaller than half the energy gap is applied. No current will flow because the electrons on the left face either filled or forbidden states on the right.* (b) *Electrons in the range eV-ϵ can flow into the superconductor on the right.* (c) *Current-voltage characteristic. When the applied voltage is just a little larger than half the energy gap the current will increase faster than when the voltage is much larger than half the energy gap. It turns out that the transition probabilities for the electrons are proportional to the density of states in the super conductor.*

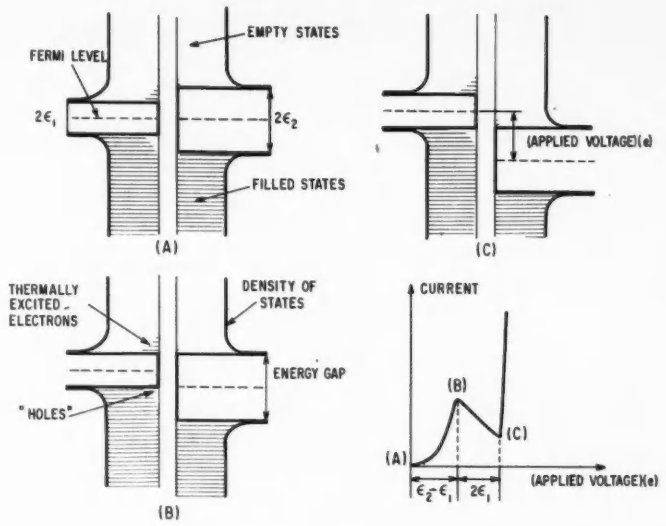


FIG. 6. *Tunnelling between two unequal superconductors.* (a) *The two superconductors with no voltage applied. Thermally excited electrons above and holes below the gaps are shown, and we may, as far as this experiment is concerned, compare the superconducter to an intrinsic semiconductor.* (b) *When a voltage is applied, a current will flow because it becomes energetically possible for more and more of the thermally excited electrons in the left superconductor to flow into the superconductor at the right. In the case pictured, all the thermally excited electrons at the left may flow into the superconductor at the right.* (c) *When the voltage is increased further, only the same number of electrons may flow, but now they face a lower and therefore less favourable density of states in the right-hand superconductor. Thus the current will decrease as a function of voltage until the electrons below the gap in the superconductor at the left can flow into the superconductor at the right above the gap.*

netic fields destroy super-conductivity and return the metal to its normal state. It is less well known that an energy gap or forbidden energy range, centred at the Fermi level, is found in superconductors.[5] No electrons with energies in this range can exist in a superconductor, and if electron waves arrive with energies in the forbidden range they are reflected.

If we now cool the capacitor-like arrangement down to liquid helium temperature, the lead will become superconducting, and an energy gap

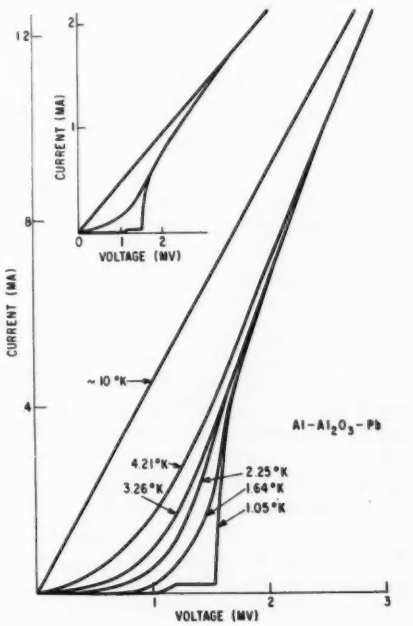


FIG. 7. *Experimental results showing tunnelling between aluminium and lead at various temperatures. At 10°K none of the metals is superconductive, between 4·2°K and 1·3°K only the lead is superconductive, and below 1·3°K both metals are superconductive. The negative resistance region is not apparent due to the current scale chosen.*

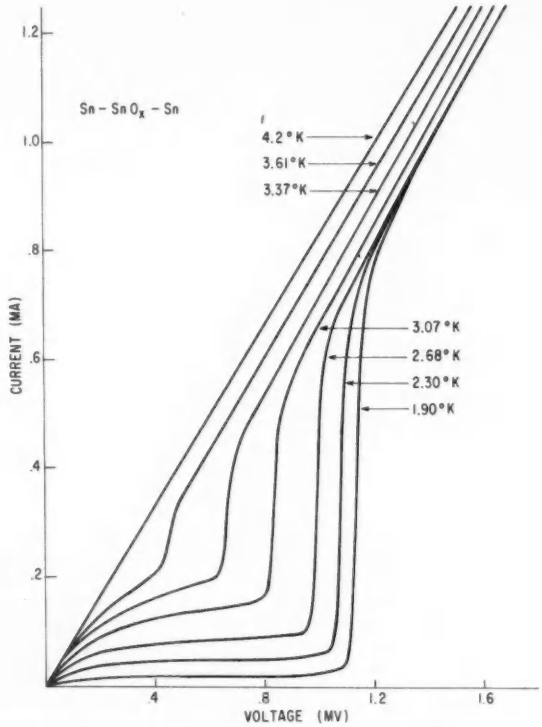
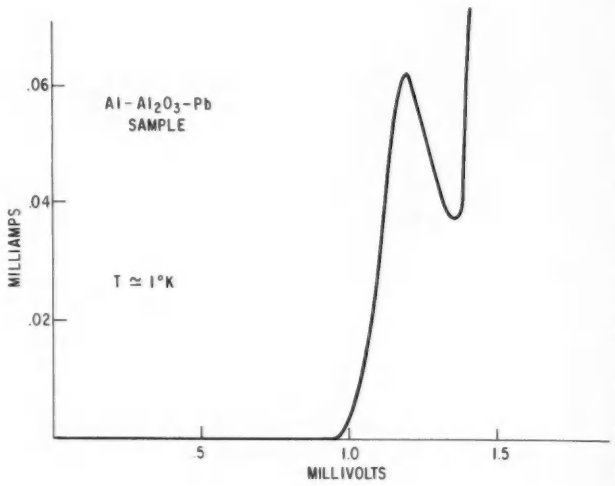


FIG. 8. *Tunnelling between tin and tin at various temperatures.*

FIG. 9. *The negative resistance region traced out for a lead-aluminium oxide-aluminium sample. The negative resistance region depends upon temperature and external magnetic field.*



will open up at its Fermi surface. Because of this energy gap the current-voltage characteristic will be nonlinear even for small voltages.[6] By studying this nonlinear characteristic it is possible to determine the actual size of the energy gap, and its dependence upon temperature and magnetic field.

By putting two superconductors together so that the electrons tunnel out from one and into the other, the nonlinear effect becomes more dramatic and a region appears where the current decreases with increasing voltage.[7, 8] Such a region is known as a negative resistance region. A negative resistance region also occurs in the tunnel diode,[9] but while the electrons there tunnel from an n-type to a p-type semiconductor, here the electrons tunnel from one superconductor to another.

A study of four superconductors,[10] namely aluminium, lead, indium, and tin, has shown that the Bardeen-Cooper-Schrieffer theory of superconductivity applies extremely well to the results of these experiments. The magnitudes of the energy gaps, the density of states (the distribution of electrons per unit energy range), and the temperature dependence of the energy gap, all agree closely with their theoretically predicted values.

Apart from contributing to the knowledge of superconductivity, it is possible that these new characteristics obtained by tunnelling into superconductors may find practical applications. Since the properties of a superconductor are influenced by a magnetic field one can operate the capacitor-like device as a switch, and possibly as a triode. The negative resistance characteristic may have application as a memory element. It turns out that the device works well as a thermometer for low temperatures, and since it is very temperature sensitive it may work well as a detector for radiation. However, the practical aspects of the process of tunnelling into superconductors are still of a highly speculative nature, and only the future can show what kind of applications they really may have.

ACKNOWLEDGEMENTS

I wish to thank J. C. Fisher for his interest and encouragement, particularly in the early stages of this work, and I want to emphasise the important part K. Megerle has played in carrying the work through to its present stage.

REFERENCES

[1] Any introductory text-book to quantum mechanics, for example: Schiff, L. I.,

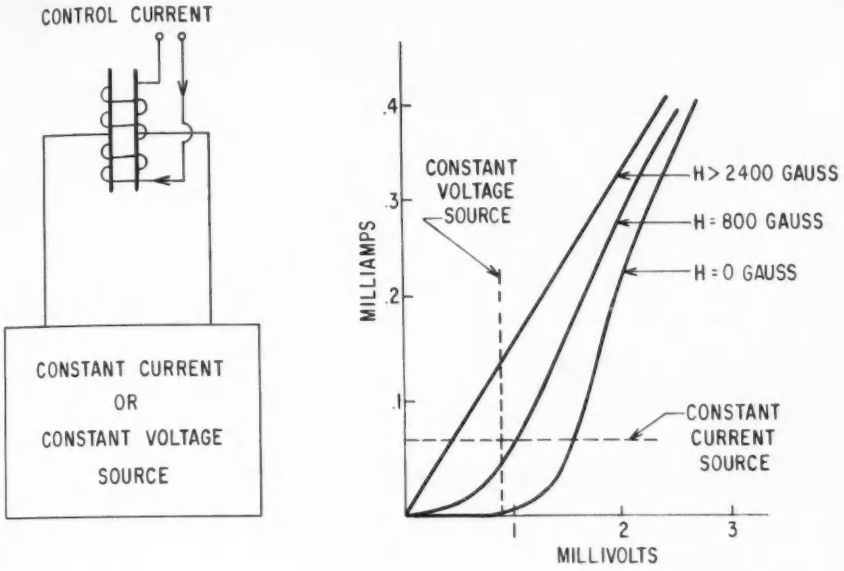


FIG. 10 *(left). This shows in principle how one can operate the junction as a switch and possibly as a triode. The control coil may be made of a superconducting material.*

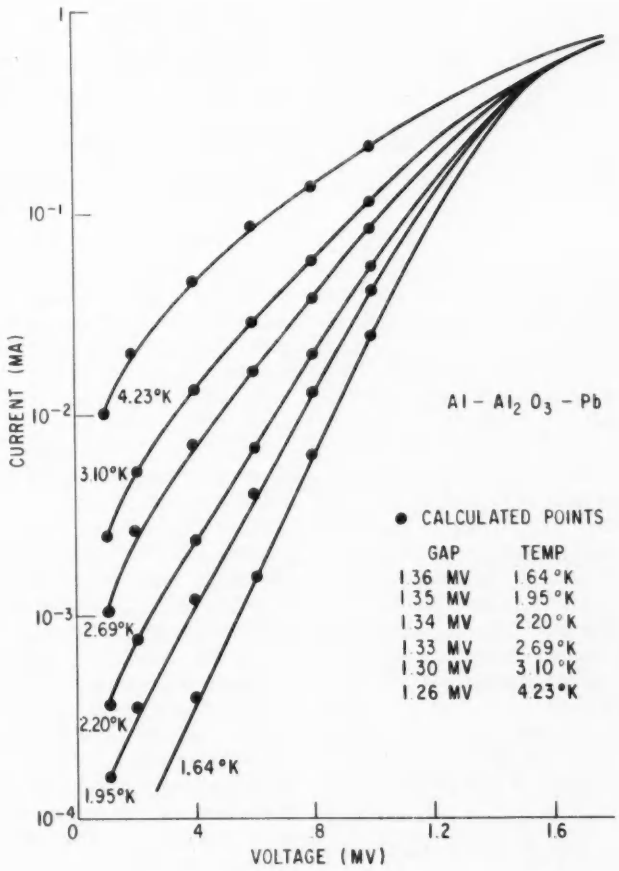


FIG. 11 *(right). Current voltage characteristic of a lead-aluminium oxide-aluminium sandwich plotted on a semi-log scale. For a certain voltage range,* $\ln I \backsim \frac{e}{kT} V$*; the inverse of the slope gives a unique measurement of temperature [e is the electronic charge, k is Boltzmann constant].*

"Quantum Mechanics", p. 92, McGraw-Hill Book Company.

[2] Fisher, J. C., and Giaever, I., 1961, *J. Appl. Phys.*, vol. 32, No. 2, pp. 172–77.

[3] Any introductory text-book to solid state physics, for example: Dekker, A. J., "Solid State Physics", p. 212, Prentice Hall.

[4] Holm, R., *J. Appl. Phys.*, 1951, No. 22, p. 569.

[5] Bardeen, J., Cooper, L. N., and Schrieffer, J. R., 1957, *Phys. Rev.*, No. 108, p. 1175.

[6] Giaever, I., 1960, *Phys. Rev. Letters*, No. 5, p. 147.

[7] ——, 1960, *Phys. Rev. Letters*, No. 5, p. 464.

[8] Nicols, J., Shapiro, S., and Smith, P. H., 1960, *Phys. Rev. Letters*, No. 5, p. 461.

[9] Esaki, L., 1958, *Phys. Rev.*, No. 109, p. 603.

[10] Giaever, I., and Megerle, K., May 15, 1961, *Phys. Rev.*

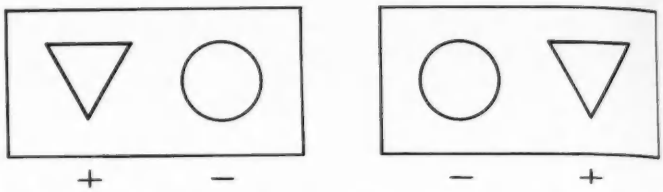


FIG. 1*a. An object-discrimination problem. Under the object marked (+)— always the same object—the animal finds food. The two arrays are presented randomly from time to time, to discover if and when the animal learns to identify which object covers the food.*

THE DEVELOPMENT OF PROBLEM-SOLVING ABILITY

IAN M. L. HUNTER

Experiments already conducted on animals and children suggest that there is a common pattern in the development of problem-solving ability. But much research remains to be done, particularly on the relationship between the development of linguistic ability and the development of problem-solving ability

Adults solve many problems which infants cannot. This is true of humans, apes, monkeys, dogs, rats—in fact of all animals. Clearly problem-solving ability develops with the advance of age towards maturity. That is, it undergoes *biographical* development. Clearly too, the courses of this development are determined jointly by the inherited potentialities of the person or animal and by his interactions with the world around. And as he becomes more experienced and intelligent, the nature of his learning and his problem-solving depend increasingly on the cumulative effects of earlier learning and problem-solving.

Anyone who has helped to rear a child or train an animal knows that the development of problem-solving is marvellously intricate and complex. It alters subtly and profoundly through infancy, childhood, adolescence and maturity. But running through this many-sided biological growth, there seems to be a broad general pattern.

This pattern can be summarised as follows. Development involves the building up of conceptual or cognitive systems. It is not the accumulation of specific, stimulus-response connexions. The main thing is the elaboration of systems which, physiologically speaking, are neither sensory nor motor. They are central processes that co-ordinate and regulate interlocking sequences of activity.

Originally, these cognitive systems are built up slowly, gradually, through prolonged learning. But once they have been built up, they can be elicited with great readiness. Furthermore, they can combine rapidly together to generate novel super-ordinate systems. In short, the broad developmental pattern—and the theme of this article—is that the complex and skilful, insightful and planful problem-solving that is achieved by adults comes from the cognitive systems built up by earlier and slow, gradual learning.

Before pursuing this theme, it may help to cite a familiar instance of a cognitive system. Present someone with two numbers, say 98765 and 43210. Ask him to multiply them. And watch what he does. He engages in a sequence of planned activity phases. His moment-by-moment doings are determined by the particular digits and also by the cognitive system elicited by the problem presented.

This system has three conspicuous properties. Firstly, it is general and schematic. It does not derive from the specific numbers presented, although

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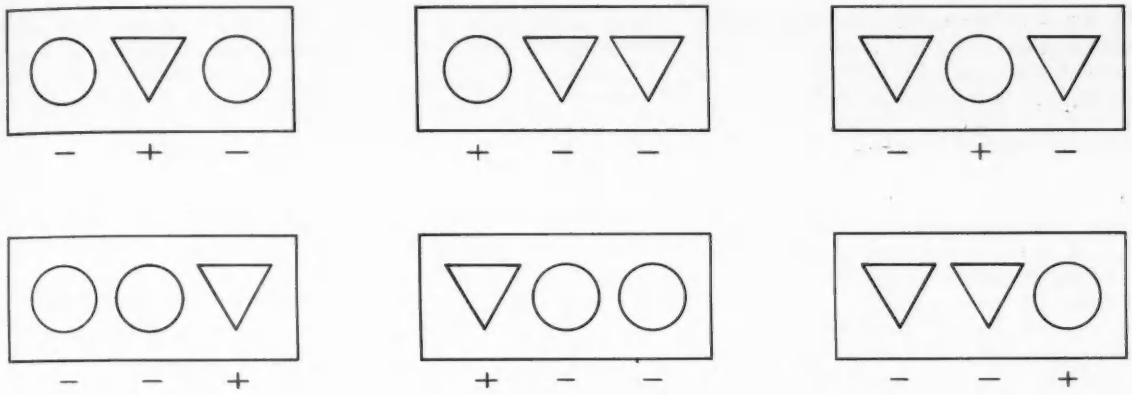


FIG. 1b. *An oddity problem showing six arrays which are presented randomly from trial to trial. To find the food, the animal must learn to select the odd object, irrespective of its nature or position.*

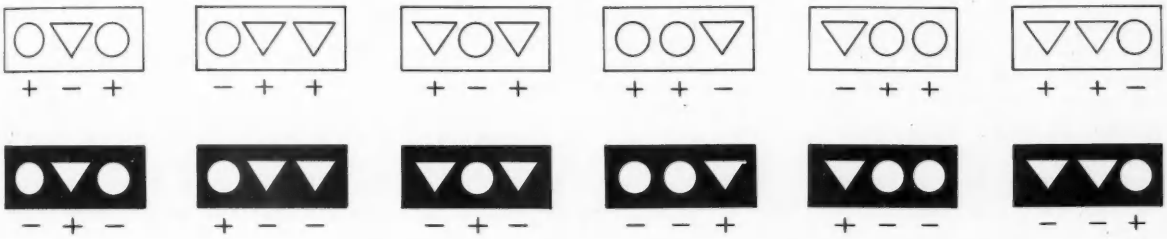


FIG. 1c. *An oddity-nonoddity problem showing the twelve arrays which are presented randomly from trial to trial. To find the food, the animal must learn to select the odd object when the tray is of one kind, say, black, and to select the non-odd object when the tray is, say, white.*

they affect its detailed carry-through. The system can equally well "process" different numbers; also, the same numbers can be used in a different system, such as "adding" or "dividing", to yield a different final outcome.

Secondly, the system co-ordinates a variety of activities into a coherent whole which extends over time, in this case for seconds or minutes. Thirdly, it derives from and is a synthesis of various past activities and experiences in the person's biography.

The developmental pattern mentioned above is suggested by a wide variety of studies in problem-solving. These studies concern humans and animals in many different situations, sometimes under natural conditions, sometimes under artificial experiment. Some involve rearing animals in severely restricted environments, some the provision of lengthy specialised training. It is this latter type of study to which we now turn—firstly to the studies by H. F. Harlow and his colleagues at Wisconsin University of what is called learning-set.[1]

Learning-set in Monkeys

A monkey is presented with a tray on which there are two easily discriminable objects (Fig. 1a). Each object covers a food-well and in one of these is a piece of food. The monkey is allowed to displace one object. If he displaces, say, the circle, he uncovers food and takes it; if he displaces the triangle, there is no food and the tray is withdrawn.

This is the first trial (a performance which is itself the outcome of considerable pre-training). Each subsequent trial follows the same pattern. The same two objects are presented, although their positions are changed randomly from trial to trial, and the monkey is allowed to displace one of the objects.

The rule of the game is that food is always under the same object irrespective of its position. This rule is more difficult to discover than its brevity suggests. The monkey requires perhaps 50 to 100 trials before he consistently displaces the right object.

Once he has mastered this problem, what happens if he is presented with a second problem involving the same rule but two new objects? Does he solve it rapidly through a general rule? Or is his learning specific to the objects used so that he has to learn all over again? The latter is the case. Typically, he requires as many trials to solve this new problem as he did to solve the previous one.

We now proceed to give the monkey a long succession of problems, some

two hundred or more, each involving the same rule and a new pair of objects. We find that he *gradually*, very gradually, requires fewer trials to master each problem until, at length, he reliably solves each new problem forthwith.

On the first trial of each problem, his choice has, of necessity, a 50–50 chance of being correct. But on the second trial, his choice is now correct every time or very nearly so. This rapid mastery contrasts with his laborious attempts at solving the preceding problems, yet it clearly derives from the cumulative effects of these earlier experiences.

He has now learned how to master new problems of this type, has built up a cognitive system which might be expressed in words as follows: "If the object chosen on the first trial is correct, it is correct on all succeeding trials; if wrong, the other object is correct on all succeeding trials." This is the system which is now so readily elicited by the presentation of each new pair of objects; which regulates his activity over a succession of trials; which summarises a long history of past experience; which was built up slowly and gradually; and which now makes possible a rapid solution of new problems.

The Pattern of Development

The sequence of events outlined above provides what seems to be the common pattern of problem-solving development. The dependence of rapid, skilful solving on slow, earlier learning is by no means peculiar to monkeys tackling two-object discrimination problems. Rather, it seems to be a universal feature, whatever the species and whatever the problem.

For example, chimpanzees[2] and preschool children[3] have been given problems where an attractive object lies outside manual reach, and can only be got by being raked in with a stick. It appears that this kind of problem is not solved without prior opportunity to learn that sticks can be used as a functional elongation of the arm.

This is shown with especial clarity by Birch's experiments, for the biographies of his four-year-old chimpanzees are known from birth. Without opportunity to learn the properties of sticks through

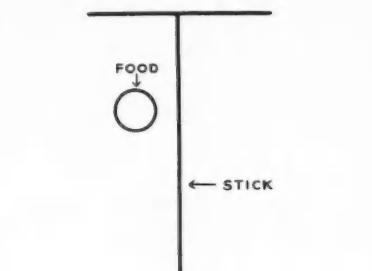


FIG. 2. *The problem used by Birch to show the spatial relations involved in using a stick-as-elongation-of-arm to rake in food that had been placed out of reach. Chimpanzees without earlier experience of sticks failed to solve this problem in a 30-min. period.*

progressive try-and-check manipulations, these animals fail to solve a simple rake-in type of problem (Fig. 2). But given such experience, they solve the problem with a speedy, deft, and genuinely novel movement sequence, which seems to involve the synthesis of at least two cognitive systems, namely, manual prehension and stick-as-elongation-of-arm.

This sequence of slow try-and-check acquisitions leading up to rapidly successful co-ordinations of activities in novel situations is also exemplified in detailed studies of children's reactions to spatial relationships—the prehension of infants,[4] the understanding of elementary shifts in object position by pre-school children,[5] and the co-ordination of disparate spatial viewpoints by four- to nine-year-olds.[6]

These studies also serve to illustrate that thinking cannot be regarded as a quality or faculty which makes a sudden entrance: intellectual development comprises a progressive increase in organisational complexity which varies, without distinct break, from the rudimentary, anticipatory learning of the first weeks of life onwards.

This sequence is also supported by the so-called sensory deprivation experiments with animals. If normal, mature activity comes from cognitive systems slowly built up from experience in a normally varied environment, then marked inferiority in problem-solving ought to result when animals are reared in restricted environments, allowing little opportunity for patterned vision, touch, and exploration. Such indeed is the case, often dramatically so.[7, 8]

Differences between Species

If we repeat the lengthy two-object learning-set experiment with different species, the main outcome is always the same, that is, the cognitive system builds up gradually. But there are marked species differences in the rate of this build-up and in the level it ultimately reaches. Kindergarten children far outdo monkeys who, in their turn, outdo sub-primates.

Miles[9] worked with rhesus macaque monkeys, squirrel monkeys, and marmosets under directly comparable experimental conditions. Each animal received a total of six trials on each of a succession of two-object problems. The macaques built up learning-set more rapidly than the others. Thus, over problems 210 to 400, the percentage of correct choices on the second trial of each new problem was about 90, 60, and just over 50 for the three species respectively.

Furthermore, the three species attained different levels of cognitive achievement at the time when they ceased to show much further improvement: after 1000 problems, the squirrel monkeys were making a steady 80% correct choice on the second trial of each problem and the marmosets had levelled off at 75%.

That species differ in the complexity of the cognitive organisation they can attain is further illustrated by the three problems shown in Fig. 1.[10] The two-object problem (Fig. 1a) is mastered by a wide range of animals including fish, mice, rats, pigeons, cats, dogs, monkeys, apes, and humans.

The oddity problem (Fig. 1b) requires selection of the odd object irrespective of its position or nature; and there is no very convincing evidence that it can be mastered by sub-primates. Also, the youngest of the children who can solve the two-object problem find the oddity problem beyond their capacity.

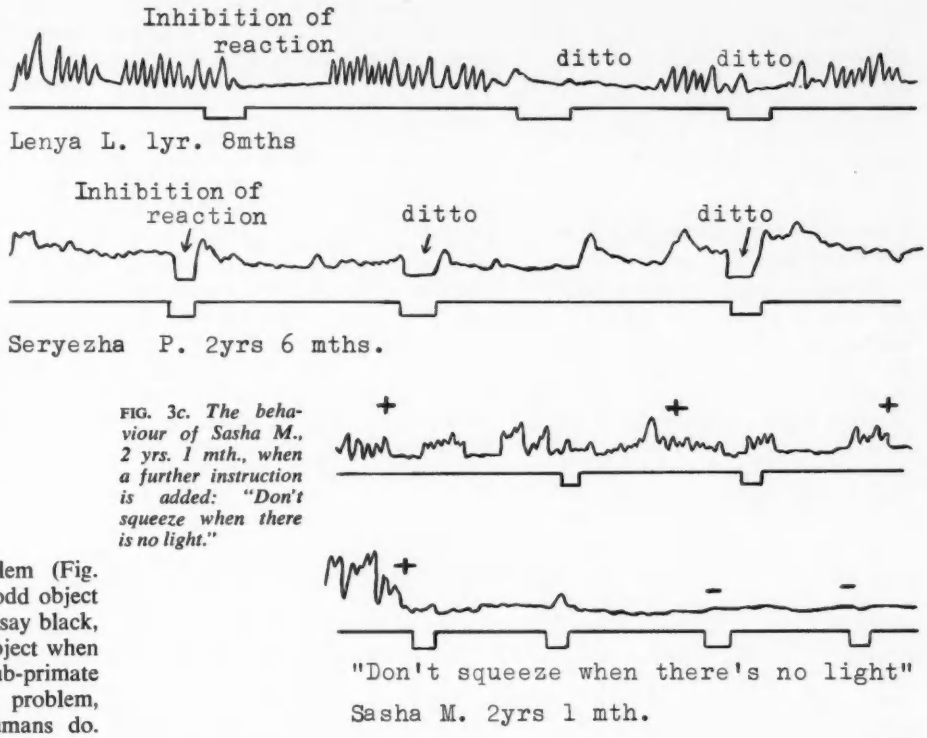


FIG. 3a. *The behaviour of Lenya L., 1 yr. 8 mths., when told: "When you see the light, squeeze the bulb."*

FIG. 3b. *The behaviour of Seryezha P., 2 yrs. 6 mths., when given the same instructions as in Fig. 3a.*

Children's responses in the light-and-rubber bulb situation, explored by A. R. Luria of Moscow University.[10] Movement in the upper line of each time trace is produced by pressure on the rubber bulb being held in the child's hand. A dip in the lower time trace indicates when the light is flashed on.

FIG. 3c. *The behaviour of Sasha M., 2 yrs. 1 mth., when a further instruction is added: "Don't squeeze when there is no light."*

The oddity-nonoddity problem (Fig. 1c) requires selection of the odd object when the tray is of one kind, say black, and selection of a nonodd object when the tray is, say, white. No sub-primate approaches mastery of this problem, but monkeys, apes, and humans do. Within these species there are even some adults who cannot solve problems of this complexity.

These results illustrate a general conclusion on the difference between phylogenetically "lower" and "higher" species. This difference does not lie in the rapidity with which simple stimulus-response habits are learned.[11] It lies rather in the organised complexity which can eventually be built up, that is in the development of cognitive capacity.

The "higher" the species, the greater the capacity to summarize more and more past experiences into a greater variety and complexity of cognitive systems; the greater the capacity to "hold together" larger amounts of problem data; and the greater the capacity to co-ordinate a larger number of his own activities into a coherent plan of action. Progressive increase in cognitive capacity is also a basically pervasive feature of human development from infancy to early maturity.

Stimuli which Elicit Systems

In the oddity-nonoddity problem, the colour of the tray plays an important role. After training, it acts as a symbol in the sense that it rapidly elicits a previously built-up cognitive system. A black tray brings the oddity-system into play and a white tray signals the non-oddity-system. But this is not the only role of the tray's colour, for it can also be demonstrated that, during training, the presence of these different trays facilitates the formation of the oddity and nonoddity systems.[12]

In short, these visual objects serve as stimuli which are effective in both the formation and elicitation of cognitive systems. It seems to be a general rule that systems are much more easily built up and, subsequently, much more rapidly elicited if they can be related to a symbol.

This general rule is as true of children as it is of monkeys. In children, however, the commonest symbols are not visual objects but vocally produced auditory patterns, that is, words and phrases. Even in young humans it is vocal stimuli which, more often than any other stimuli, elicit regulating cognitive systems, summarising many past experiences. And this circumstance has many advantages of which three are especially obvious, even if we continue to consider only the trainer-trainee relationship.

Firstly, it is literally easier for the trainer to carry the symbols around if they are vocal utterances rather than coloured trays and other objects. Secondly, the trainer can get his trainee to respond to an auditory symbol provided only that the trainee is within earshot; he does not have to be oriented towards the stimulus source, as he must be with visual objects. Thirdly, vocal utterances form part of an elaborate, generalised, socially shared, man-made system (language) which has rules of combination; and once the trainee has learned some of these rules, the trainer (any trainer who knows the language and even the trainee himself) can rapidly elicit novel super-ordinate prescriptions for activity by uttering a compound command—provided the command does not contain more component symbols than the trainee can integrate together.

It may seem that the above points are cumbersome, perhaps facetious formulations of platitudes. If so, it is because our everyday familiarity with human activity obscures for us the

marvellous intricacy of its organisation. Perhaps an example of child activity will serve to illumine something of this intricacy. This example concerns a situation much used by Soviet investigators and is adapted from a report by A. R. Luria of Moscow University.[13]

Children's Reactions to Verbal Instructions

A normal and co-operative six-year-old child is seated at a table. On the table is an opaque box with a ground-glass front. Inside the box is a light which we can switch on and so illumine the glass panel. We show the child the light, give him a small rubber bulb to hold in his hand, and say to him "When you see the light, squeeze the bulb". We then flash on the light from time to time. What happens? Each time the light goes on, he squeezes the bulb; and when the light is off, he does not squeeze. This behaviour seems unremarkable—until we compare it with the reactions of a younger child. When a normal two-year-old is placed in the same situation and given the same instructions, his behaviour is *the exact opposite*, that is, he repeatedly squeezes the bulb and only stops doing so when the light comes on (Figs. 3a and 3b).

This strange behaviour of the two-year-old stems initially from his responding to our instructions in piecemeal fashion. "When you see the light . . ." elicits a looking toward the panel. ". . . Squeeze the bulb" initiates a manual squeeze which, at this age, persists as a repetitive succession of squeezes. (Just why there should be this squeeze-release-squeeze cycle is an interesting question but, here, the cycle must simply be recorded as a fact.) Then, when the light comes on, this elicits what is called an orienting response.

This kind of response, which pervades the activities of animals and humans, is elicited by any relatively sharp environmental change, and involves alterations in sense organs, muscles, central nervous system, and blood flow.[14] Its biological value is that it prepares the organism to deal with the potential emergency of the environmental change: its relevance to the present situation is that it disrupts ongoing activities. The child is engaged in repetitive squeezings as a result of being given instructions; then the light elicits an immediate orienting response; the squeezings are, for the time being, suspended.

The difference between the six- and two-year-old child is not that one reacts to our verbal utterance while the other does not. The difference is that the older child reacts to the utterance as a co-ordinated whole while the younger, with his poorer cognitive capacity, reacts to it as two unrelated parts.

It might be thought that we could make the two-year-old behave like the older child by adding yet another instruction. So when the light is off, we say to him, "Don't squeeze when there is no light". However, this "reminder" does not have the intended effect. Either it intensifies his squeezing, as would the bare instruction "Squeeze"; or it brings about cessation of all manual activity (Fig. 3c).

These effects of the added instruction further emphasise the part-by-part, non-integrative reactions of the younger child to the events in the world around him. In contrast, our utterance *rapidly* creates in the older child a *new* and *composite* cognitive system which regulates his activities throughout the course of the task.

Effect of Species Difference on the Learning of Language

The normal adult speaks and comprehends the speech of others, he writes and he reads. His linguistic activities are not separate from his other activities and, like those others, they derive from long biographical development. Yet his language is, as much as anything, what distinguishes him from all other animals. Why should this be?

It is not that animals lack all vestige of language. Many animals communicate with other members of their species by vocalising, as well as by visual signals. Nor is it that animals cannot learn to respond selectively to different utterances, for every animal trainer knows that they can. The superior linguistic acquisitions of humans seem to derive, in brief, from their greater cumulative learning capacity coupled with an inherited disposition to engage both in vocal play and in vocal imitation.

These two human characteristics are vividly illustrated by Kellogg and Kellogg,[15] whose delightful and informative book reports the outcome of rearing an ape and a child together as members of the family. At the start of the experiment, the female chimpanzee, Gua, was 7½ months; the male child, Donald, was 10 months. For nine months, the two "children" were playmates. They were treated alike in every way possible—dressed, bathed, taught "manners", played with, talked to, taken for car trips. So it was possible to study their development in comparable environments.

With regard to language, Gua, though younger, was the first to learn appropriate, selective responses to purely vocal commands—that is, commands spoken while she was not looking at the speaker. At two, four and five months after adoption, Gua's repertoire was 7, 14 and 21 different "known" commands while Donald's was 2, 8 and 20. Donald lagged behind Gua to start with, but he later caught up and soon expanded his repertoire rapidly while Gua's increased hardly at all.

The language difference between Gua and Donald was even more striking with regard to spontaneous vocal play and imitation. From the earliest months, Donald, like all normal children, cooed, hummed and, later, babbled. He acted almost as if he were practising the formation of new vocal patterns.

Gua, despite her more mobile lips and tongue, made no attempts to produce utterances beyond those few which she had on arrival. Nor did Gua imitate the vocalisings of those around her, whereas Donald imitated, with increasing frequency, both his parents and Gua.

Painstaking efforts to train Gua to say "Papa" had little success and the Kelloggs suggest that possibly no ape, no matter how favourable the environment, could learn to speak above half a dozen words.

This suggestion is supported by Hayes and Hayes.[16] This childless couple took a newborn chimpanzee, Vicki, into their home and reared it as they would a child. After three years, Vicki could, on occasion, "meaningfully" say the words "Papa", "Mama", and "Cup". But this was the limit to the utterances of this highly privileged member of the species which is among man's closest living relations.

Language and Problem-solving

The linguistic achievements of chimpanzees are far inferior to those of man. Their overall problem-solving achievements are also inferior. How far, then, does human problem-solving owe its accomplishments to cumulatively acquired linguistic skills?

Suppose that a potentially normal human is reared in a reasonably normal and varied environment. Suppose that, through deafness, he does not acquire language. Would his problem-solving be no better than a chimpanzee's?

Obviously he could not solve verbal problems, that is problems posed in words and requiring changes, in accordance with linguistic rules, to obtain verbal solutions. But granted this, could he rapidly and skilfully solve problems which chimpanzees could solve, if at all, only after long and specialised training? The answer is that he can.

Congenitally deaf infants engage in vocal play but, soon, their vocalisings diminish to reappear mostly in moments of emotional excitement. In the absence of very special training, they do not learn to speak, do not acquire language.

This severely handicaps social communication, yet they do develop intellectually. Their teachers have long known that if a deaf-mute is, at say six years, taught language for the first time, this is often a matter of his learning verbal symbols for cognitive systems that are already built up.[17]

In Paris, P. Oléron[18] has made detailed comparisons of deaf-mute and hearing children in various problem situations. Both groups of children, some 60 in each, were aged from four to seven years and included no children who were markedly retarded or brain-injured. The problems given to them were non-verbal but complex enough to tax the abilities of the normals and certainly complex enough to give chimpanzees severe difficulty at the least. The broad finding was that, age for age, the deaf-mutes performed as well as the hearing children in most of the problems. So problem-solving processes can attain considerable sophistication without the aid of language.

This does not mean that language exerts no influence on the development of thinking processes. The fact that language is the chief, and a very effective medium for instruction and education shows that it does. Even with Oléron's children, there are some qualitative differences between the groups; and in one particular problem a linguistic symbol seems necessary for solution. This is Double Alternation, a two-object discrimination problem where the positive object is, irrespective of its nature, on the right side for two trials, then on the left side for two trials, then right for two trials, and so on.

It appears that this problem cannot be solved by any child who has not acquired a symbolic response for "two". The suggestion is that this response must literally enter into the sequence of problem-solving events if solution is to be attained.

Considerations such as these serve to indicate that the relations between linguistic and problem-solving development are complex, and that there is scope here for painstaking research. This has scarcely begun, but it is clear many surprises are in store.

The difference between the lower and the higher species does not lie in the rapidity with which certain stimulus-response habits are learned. It lies rather in the organised complexity which can eventually be built up, that is, in the development of cognitive systems. It seems to be a general rule that systems are much more easily built up and, subsequently much more rapidly elicited, if they can be related to a symbol.

REFERENCES

[1] Harlow, H. F., 1949, "The formation of learning sets", *Psychol. Rev.*, *56*, 51–65.

[2] Birch, H. G., 1945, "The relation of previous experience to insightful problem-solving", *J. Comp. Psychol.*, *38*, 367–383.

[3] Matheson, E., 1931, "A study of problem solving behavior in pre-school children", *Child Development*, *2*, 242–262.

[4] Gesell, A., *et al.*, 1940, "The First Five Years of Life", New York: Harper, London: Methuen.

[5] Meyer, E., 1940, "Comprehension of spatial relations in pre-school children", *J. Genet. Psychol.*, *57*, 119–151.

[6] Piaget, J. and Inhelder, B., 1956, "The Child's Conception of Space", London: Routledge & Kegan Paul.

[7] Beach, F. A. and Jaynes, J., 1954, "Effects of early experience upon the behavior of animals", *Psychol. Bull.*, *51*, 239–263.

[8] Riesen, A. H., 1958, "Plasticity of behaviour: psychological aspects", in "Biological and Biochemical Bases of Behavior", edited by H. F. Harlow and C. N. Woolsey, Wisconsin University Press.

[9] Miles, R. C., 1957, "Learning-set formation in the squirrel monkey", *J. Comp. Physiol. Psychol.*, *50*, 357–359.

[10] Harlow, H. F., 1958, "The evolution of learning", in "Behavior and Evolution", edited by A. Roe and G. G. Simpson.

[11] Hebb, D. O., 1949, "The Organization of Behavior", New York: Wiley, London: Chapman & Hall.

[12] Harlow, H. F., 1951, "Thinking", in "Theoretical Foundations of Psychology", edited by H. Helson, New York: Van Nostrand.

[13] Luria, A. R., 1961, "The Role of Speech in the Regulation of Normal and Abnormal Behaviour", London: Pergamon.

[14] Berlyne, D. E., 1960, "Conflict, Arousal, and Curiosity", London: McGraw-Hill.

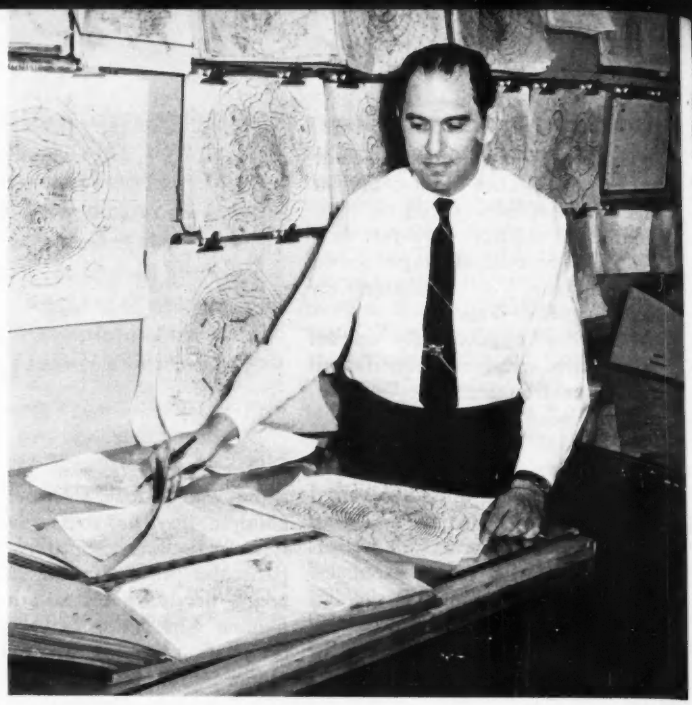
[15] Kellogg, W. N. and Kellogg, L. A., 1933, "The Ape and the Child", London: McGraw-Hill.

[16] Hayes, K. J. and Hayes, C., 1951, "The intellectual development of a home-reared chimpanzee", *Proc. Amer. Phil. Socy.*, *95*, 105–109.

[17] Heider, F. K. and Heider, G. M., 1940, "Studies in the psychology of the deaf", *Psychol. Monog.*, *53*, No. 232.

[18] Oléron, P., 1957, "Recherches sur le Développement Mental des Sourds-muets", Paris: Centre National de la Recherche Scientifique.

The problems of long-range forecasting are now being attacked by mathematical physics. They are yielding gradually, and with an economic return sufficient to justify the charting of the atmosphere of the whole earth's surface, even at a cost of £100 million per year



Jerome Namias of the United States Weather Bureau, surrounded by charts used in formulating his 30-day forecasts.

PROSPECTS FOR CONTROLLING AND FORECASTING THE WEATHER

R. C. SUTCLIFFE

The ability of mankind to control his environment, physical and biological, is, I suppose, the secret of his success on earth but, in spite of the efforts of priests and witch doctors through the ages, there is no evidence that anything of significance has ever been achieved in attempts to alter the weather. Mankind has been forced either to protect himself against its rigours or migrate elsewhere for survival, and this remains true to this day.

This is the second article by Dr Sutcliffe, Director of Research at the Meteorological Office. The first, on "Unsolved Problems of Weather and Climate", appeared in the July issue.

LOCAL ATTEMPTS AT CONTROL

Yet in recent years there has been a new wave of attention to the subject, even by sober-minded scientists, prompted by the fact that, for a time, there did seem to be every chance of doing something worth while. In many parts of the world where rainfall is deficient or where additional rain could be put to good use, there may often be heavy clouds in the air which pass by and dissolve without giving much rain.

The explanation takes us deep into that field of meteorological science which we call cloud physics. The clouds in the free air, as is fairly obvious to anyone who has flown through them, are much the same physically as a wet mist on the ground or a mountain fog. They are composed of tiny droplets, a thousand to the thimbleful, too small to fall to the earth individually and remarkably reluctant to join together to make a raindrop. Actually they do collide and combine, slowly at first and then more rapidly; if a cloud lasts for about half an hour some large drops will fall out but many clouds die before they have time to rain.

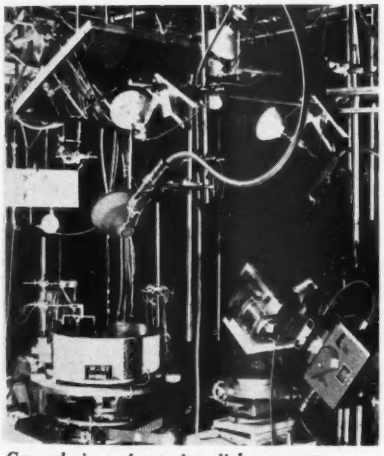
There is, however, a way in which some clouds may be helped along,

provided that their temperature falls well below freezing-point. The droplets do not freeze readily but, if stimulated or seeded with ice particles thrown off by pellets of solid carbon dioxide or triggered off by particles of silver iodide, the freezing may proceed rapidly and the ice particles then grow and fall through the cloud, picking up the supercooled water droplets; and so rain may be quickly stimulated.

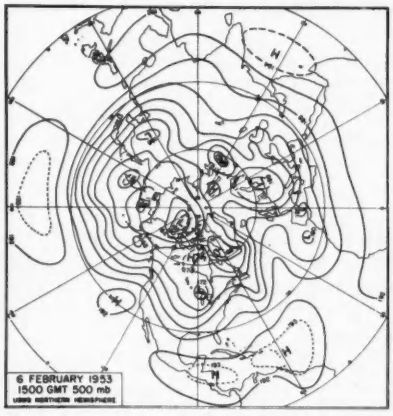
This certainly can be made and seen to happen with suitable isolated clouds, and great excitement prevailed for a time at the prospect of achieving something on the economic scale. Especially in America, enterprising business operators were soon prepared to offer their services as rain-makers, at a price; millions of dollars changed hands in a few years and, if it was difficult to prove success, it was equally difficult to prove that seeding operations had had no effect.

The trouble, as anyone might imagine, is that of distinguishing between artificial rain and natural rain which would have fallen in any case. Witch doctors of old no doubt knew this difficulty and were ready to claim anything which followed their incantations but, today, there are methods of statistical analysis carefully designed to disentangle this kind of confusion and after about 15 years of trials of many kinds, the position is frankly discouraging.

Over mountainous country where suitable clouds may be found very frequently, the weight of evidence is that seeding has increased rainfall to some slight extent but the economic value of the process even there is dubious and the whole subject has become less fashionable in the last year or two. It is a disappointing outcome to a very promising idea but much has been learned of cloud physics in the meantime.

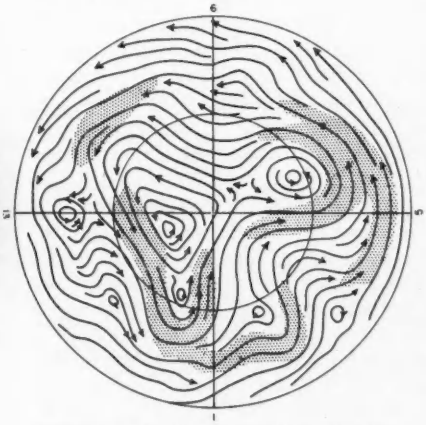


General view of rotating dish apparatus.



A world weather map similar to the streamlines of water in the dish.

Streak photograph of motion of water in the dish.



Streamlines sketched from the motion of water in the dish.

LARGE-SCALE IDEAS FOR CONTROL

Ideas for altering weather and climate on the large scale by altering the tracks of depressions, by clearing away ice and snow fields, by warming up the Arctic Ocean and by modifying the general circulation of the atmosphere have been seriously put forward and equally seriously attacked as impracticable, leaving no accepted doctrine on the subject.

The direct attempt to change the weather by competing with the sun in its control of our climate is vain and foolish, for the cost of the energy lavishly expended by the sun in evaporating water to maintain the supply of rain to the earth would, at present electricity prices, approach a million pounds per year for every man, woman and child on earth. If we are to control this colossal heat engine, we must study its mechanism and be very subtle and, so far, no-one has suggested anything which is more subtle than heaving a spanner in the works.

Some American writers believe that the Russians are feverishly studying how to warm up the Arctic, and certainly a scheme which involves blocking up the Bering Straits between Alaska and Siberia and pumping the cold water into the Pacific was put forward in Russia. But this scheme was openly and vigorously attacked in the country of its origin on the double argument that, first, it would not work and second, that if it did, it would be a disaster for much of Russia.

Certainly on the knowledge we yet have, any large-scale modification of climate intended to be beneficial in one area would in every likelihood be harmful elsewhere and, knowing that scientists are constitutionally unable to control their own curiosity and will go on thinking and experimenting, even

By careful scaling the motion of water in a rotating dish heated near the rim is similar to that of the atmosphere on a rotating Earth heated near the equator. The diagrams give a view of the apparatus as used by Fultz in Chicago University, together with an example of results obtained. *(Photos: Meteorological Monograph Number 21 of Volume 4, titled "Studies of Thermal Convection in a Rotating Cylinder with Some Implications for Large-Scale Atmospheric Motions"—written by Dave Fultz, Robert E. Long, George V. Owens, Walter Bohan, Robert Kaylor, and Joyce Weil. The research was sponsored by the Geophysics Research Directorate of the Air Force Cambridge Research Centre, Air Research and Development Command, under Contracts AF 19(122)–160 and AF 19(604)–1292.)*

A Cessna aircraft flying over northern New South Wales, seeding clouds with silver iodide. Though some local successes have been achieved, Dr Sutcliffe considers that "after about 15 years of trials the prospect of creating artificial rain is frankly discouraging".

(Photo by courtesy of CSIRO Division of Radiophysics, Sydney, N.S.W.)

if the outcome may be dangerous, we need not wholly regret the lack of success. In lighter vein, it has been pointed out that the work of the weather forecaster would be even more trying than it is if there were rival teams of weather controllers also at work and, for the present, a short discussion of the forecasting of natural weather must suffice.

FORECASTING THE WEATHER

Systematic weather forecasting by technical methods which require neither magic nor second sight has been practised in the more advanced countries for about a century. The early success depended on the development of the "electric telegraph" and has throughout gone forward with the improvements in rapid communication, the telegraph, the telephone, radio, teleprinter, radio-teleprinter, facsimile transmission, television. The possibility of forecasting beyond a few hours ahead in changeable weather arises simply because the weather systems, especially depressions and anticyclones, move slowly across the map, admittedly changing their structure as they do so but broadly carrying their typical weather conditions with them.

If, therefore, we devote sufficient funds and effort to obtaining weather messages from a wide area, we may chart the weather on suitable maps, study how the patterns move and change and predict by extrapolations. Although there are many complications due to such factors as diurnal variations, mountains and valleys, land and sea distributions, man-made atmospheric pollution and a host of natural peculiarities in the behaviour of the atmosphere itself, the simple facts about the behaviour of depressions and anticyclones (outside the tropics) have made forecasting possible. At the same time they have made great improvements in forecasting seem almost impossible.

Putting it very simply, if we study any weather map, there are pressure systems present which behave reasonably coherently for one day, two days or perhaps, in favourable circumstances, a little longer but after that time they disappear, new systems take their place and, until they have begun to take shape, we can do little more than guess their behaviour in detail.

PROGRESS IN SHORT-RANGE PREDICTION

The progress of forecasting this century has been mainly in predicting the weather for a day or two ahead, with ever greater attention to detail. For aviation it has gone to greater and greater heights in the atmosphere and greater and greater distances from home, even half-way round the world.

In this development of short-range forecasting, techniques have been steadily refined as understanding of the atmosphere has advanced, but there was, until the time of World War II, one fundamental scientific weakness.

Tiros I, the first weather-eye satellite, took this picture of a typhoon centred about 300 miles north of New Zealand about 0300, April 10, 1960.

The atmosphere is a fluid in three dimensions and it can be studied thoroughly only if we know the temperatures, pressures, winds, etc., not only near the ground but far into the air above.

Balloon-borne radio equipment, the radio sonde, met the practical need and permitted a revolutionary advance in theory and in forecasting technique. Weather maps for most of the world can now be drawn every day for levels

far into the stratosphere; we have the required three-dimensional picture. The theoretician was in this way soon enabled to see how the well-known basic laws controlling all kinds of fluid motion, from ocean currents to water in pipes, had to be adapted to satisfy the ways of the atmosphere. This done, mathematical equations were constructed which, if solved, would enable us to forecast the future from our knowledge of the present.

In mathematical physics, problems often become very difficult to solve when there are many inter-related variables, and it came as something of a shock to expert weather forecasters to learn that the mathematical physicists were presuming to calculate the future weather map in spite of all the complications. As a matter of fact, their achievement has depended on two very fortunate circumstances. First, by something which is little more than a stroke of luck—a scientific fluke—it appears that a dominant factor controlling the movements of the depressions and anticyclones, which forecasters have been concerned with for 100 years, is the average speed of the wind from the ground to the stratosphere. If to this is added the average temperature, we have with only two variables the possibility of a baroclinic atmosphere sufficiently like the real one to make a start on forecasting by calculation.

The second fortunate circumstance was the invention of the high-speed electronic computer which allowed very heavy calculations to be carried out quickly and—in computing language—"in real time", a phrase very appropriate to weather forecasting, for a method which is not fast enough to keep pace with the clock is of no practical value.

In brief, by simplifying the physics to make the calculations as easy as possible and by using computers working as fast as possible, realistic forecasts have been made. In America, calculated weather maps are used as an aid to forecasting every day and in several other countries research studies are far advanced. In the United Kingdom routine daily calculations await only the necessary machine installations, although when suitable machines cost anything from £100,000 to £1 million decisions need to be taken soberly.

Obviously, further progress will be made; numerical forecasting by electronic calculation has evidently come to stay; but the complicated details of weather still remain and it will be a long time before the expert forecaster, knowing his territory in every mood of the weather, can safely be dispensed with.

LONG-RANGE FORECASTING

When the forecaster tries to look beyond a day or two ahead, many of his depressions and anticyclones literally dissolve into thin air before his eyes, others take their place and his methods of extrapolation or calculation fail. His difficulties are of a different order for not only, so to speak, must he estimate how each horse will run in the race but first he must guess which horses will come from the stables.

The forecaster can usually say something useful for as long as four or five days ahead if it is sufficient to say that the weather will remain unsettled or generally fine or will tend to become warmer or cooler. Such general persistencies or trends, which may often be discerned, are the basis of what is called medium-range forecasting, so that by long-range forecasting one implies outlooks for even longer periods, of the order of a month or a season, when no attempt at detail is possible.

There are people in the world who will attempt precise forecasting of the weather from day to day a month or even a year ahead—and some will even accept a fee for their services—but one may say with virtually the whole weight of disinterested scientific opinion behind one, that this kind of forecasting is no better than the speculations which any person could make if he knew the kind of weather typical of the place and season of the year—and in many places, including England, there is so much variety at all times of year that the speculation can be of little value.

Nevertheless, in spite of all this difficulty, it remains true that weather does go in spells, often in spells of a week or two, sometimes in spells of months, with the result, for example, that England in 1959 had a lovely summer and in 1960 no real summer at all. Here is clearly some behaviour which we do not understand, which it would be extremely useful if one could predict and which it is reasonable to hope that we might, in time, learn how to predict.

Long-range forecasting of this kind, which attempts to predict the general character of a whole month or a season, is practised in several countries by responsible persons, generally by official services, and with perhaps a modest degree of success. But there are also undisputed failures and it must be conceded that the methods used are neither reliable in practice nor understood in theory.

SOME LEADING FORECASTERS AND THEIR METHODS

Perhaps the most generally used notion is that of "analogues", which means other weather situations from the past similar to the present in one or more respects. Multanovsky made a reputation for long-range forecasting in Russia before the last war and thought in terms of natural synoptic periods, spells of weather of varying length with recognisable characteristics, although these have validity for only a few days and recent Russian writing has undermined his earlier reputation.

Prof. Baur, who introduced in Germany some thirty years ago the concept of *Grosswetterlagen*, having close affinity with the Russian natural periods, continues to issue long-range forecasts from time to time for varying periods up to a season ahead, putting considerable weight on those curious solar phenomena known as

By a stroke of luck it appears that the dominant factors in controlling the movements of depressions and anti-cyclones are only two—the average speed of wind from the ground to the stratosphere and the average temperature.

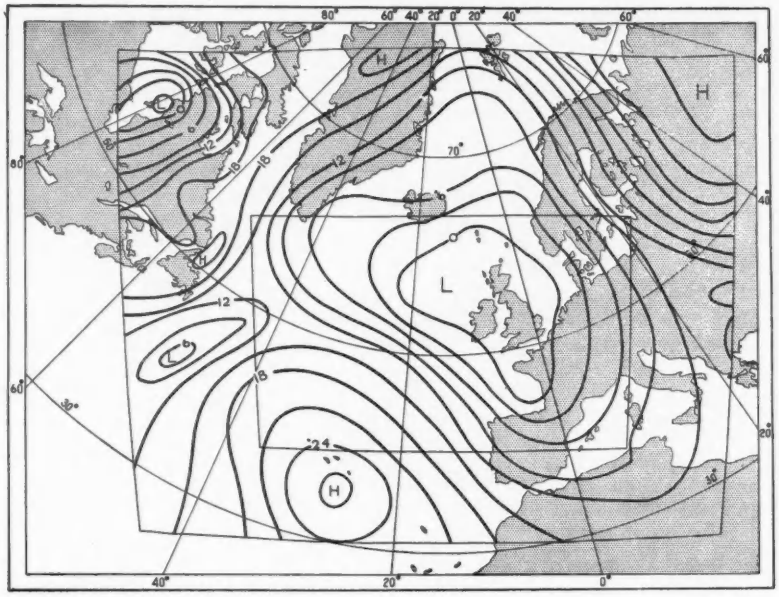


FIG. 1. *November 12, 1959.*

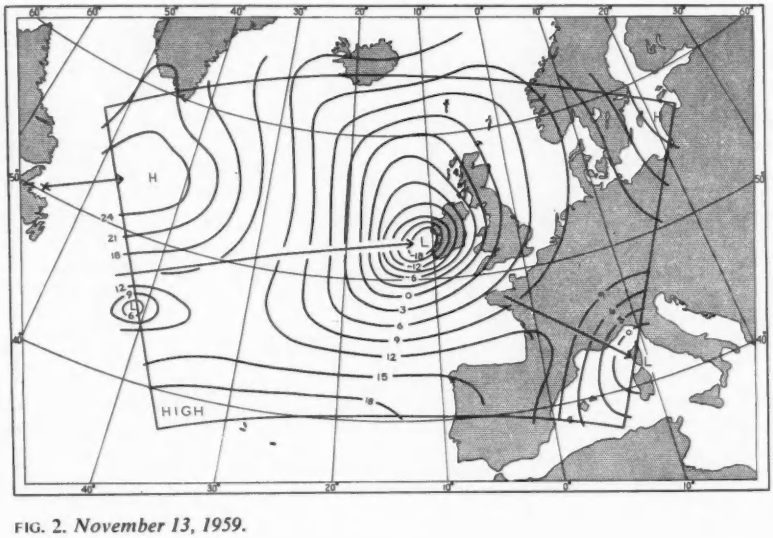


FIG. 2. *November 13, 1959.*

sunspots which vary in number over a cycle averaging something over eleven years in length. Baur relates the weather in Europe with other years when the sunspot cycle was in much the same phase at the same time of year, and by choosing also years which were analagous in other respects, arrives at a prediction.

It must be said at once that the effect of sunspots on the weather is not yet established, although their effect on the ionisation of the high atmosphere is strikingly obvious in radio-communication and in other ways.

Furthermore, Baur has difficulty in matching his years satisfactorily. Nature never repeats herself but, on the whole, the forecasts he has ventured to make in recent years, although vague and cautious, seem to have been correct as far as they went in most cases. Namias of the United States Weather Bureau is another world-famous name in this field. His forecasts of average conditions for a month ahead have been issued regularly for a number of years. The forecasts are clearly presented as maps of the northern hemisphere showing which areas will be warmer or cooler, wetter or drier than average, and they are based on a variety of indications, trends, anomaly patterns and dynamical calculations. But their accuracy, at least for Europe, is not claimed to be of much value.

In France, a specialised technique of extrapolation of pressure-time curves is employed, while in the United Kingdom in the last few years, there have been experimental monthly forecasts prepared in the Meteorological Office using a method of analogues. But again, only marginal success has yet been claimed, and the forecasts have not been offered to the public.

This is an unsatisfactory state of affairs. The practical value of reliable long-range forecasts would be so enormous for agricultural and commercial planning that more effort would be justified. The crucial question is whether the behaviour of the atmosphere is really predictable at all for long periods ahead, and this we ought to be able to discover when we have a good theory of the general circulation.

We may recall that the circulation is a kind of engine driven by solar energy against the brakes provided by friction, and if the circulation behaves differently one year from another—and it certainly does—then one could reasonably suppose that either the energy input or the brakes must be different; either the sun above or the earth below must be the seat of the variations.

This argument, plausible enough, justifies our looking to sunspots, sea temperatures, polar ice and snowfields for guides in long-range forecasting, but there is one serious difficulty related with what mathematicians call non-linearity and engineers call feed-back. About half the energy from the sun is reflected back to space immediately without doing any work, and most is reflected from the clouds. Thus a change in cloudiness can certainly cause much larger changes in the weather than any plausible changes in the sun itself.

Also looking to the lower boundary, heat and moisture are put into the atmosphere where the air is dry and

cool, relative to the sea temperature. But far greater changes may be caused by differences in the circulation itself, than by the smaller changes in the temperatures of the sea.

Thus it is possible—as the seasons change and the circulation of air goes through its annual cycle, including the monsoons, and changes in position and intensity of the jet streams—that each year the behaviour is different owing to minor past differences which have no cause, except in the sense that everything is a legacy from the past.

Nature is full of behaviours which are so complicated that they defy detailed analysis and prediction. Each tide alters the lie of the sand on the sea shore, but who would predict just what the next tide will do? Earthquakes are particularly common in certain parts of the world for reasons which are well understood, but who will say if this year is to be unusually bad in one part rather than another? Perhaps in principle one can predict the path of a raindrop trickling down a window pane or of a pebble rolling down a cliff, but would they be predictable in practice if we really needed to know?

One cannot say with certainty, for in science it is always difficult to prove that something cannot be done. No experiment can be designed to show that long-range forecasts are for ever impossible. But we may accumulate knowledge by many positive experiments, which may be of three kinds.

First, taking Nature as we find it, we may try to predict by various methods and profit by the experience; this is what has been done hitherto with only slow progress. Second, we may study the circulation by building small-scale laboratory models of the atmosphere; this has been done with much ingenuity using rotating bowls of unequally heated liquid, and has even given suggestive results, but the scaling down of the whole earth to a laboratory model while retaining gravity and atmospheric properties presents formidable difficulties.

Third, we may make mathematical models—that is, invent systems of mathematical equations which formulate many of the essential physical processes, and by calculation, test the assumptions which have been made. Recent work, especially by Smajorinsky in America, with the aid of electronic computing, has led to remarkably promising results, and it may well be that in time there will be another great achievement to the credit of mathematical physics.

It is only a matter of time and effort before the problem of long-range forecasting will be understood in a scien- of weather changes day by day will then be practicable depends on many things. Our present understanding leads us to believe that detailed statements of weather changes day by day will never be possible for many days ahead, but as regards the general character of next summer or next winter, we have no reason to despair.

In the long perspective of a hundred years of forecasting, the last fifteen years have been quite outstanding, for in this period weather science has at last taken the place to which it belongs as a branch of fluid mechanics, to be attacked by the methods of mathematical physics. Its problems are complicated and tough but are yielding gradually, and with an economic return sufficient to justify the charting of the atmosphere over the 500 million square kilometres of earth every day, even at a cost of £100 million per year.

FORECASTING BY ELECTRONIC CALCULATION

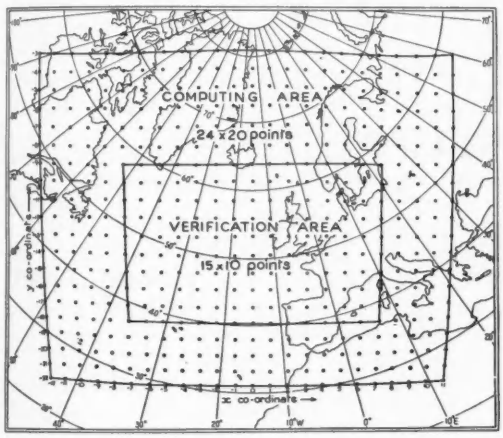


FIG. 3. *Area and grid used in numerical calculations.*

Weather charts may now be forecast 24 hours ahead by calculation using electronic computers. The chart in Fig. 4 was the forecast calculated 24 hours earlier on the basis of the chart in Fig. 1. The chart in Fig. 2 is what actually happened. The elaborate calculations are made over the area and grid shown in Fig. 3 using finite differences to solve simultaneous differential equations of the type:

$$\bar{\nabla}^2 \frac{\delta h}{\delta t} + J(h, a\bar{\nabla}^2 h') + J(h', b\bar{\nabla}^2 h) = 0$$

where h *and* h′ *are contour heights of constant-pressure surfaces,* $\bar{\nabla}^2$ *is the two-dimensional Laplacian,* J *the Jacobian, and* t *is the time.*

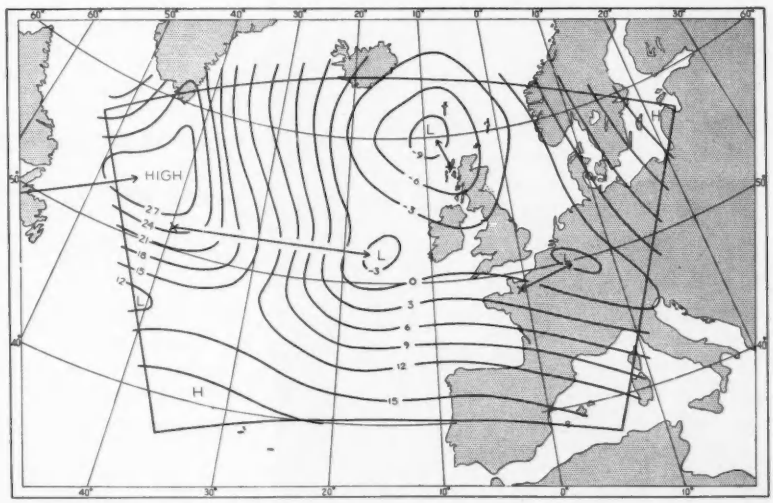


FIG. 4. *November 13 (as calculated).*

THE NEBULA IN CYGNUS *(NGC 6960), believed to be the remnant of a 100,000-year-old supernova.* *(Photo: Mt Wilson)*

THE PROSPECTS AND CONSEQUENCES OF A MAJOR STELLAR EXPLOSION

C. M. CADE

When a supergiant star explodes, it may put television, radio and other communication systems out of action for some time—possibly a year. The last such explosion in our galaxy was in 1604. But the Chinese have studied records going back 2500 years which suggest that a supernova is likely to occur in the Milky Way once in every 150 years

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When beggars die there are no comets seen;

The heavens themselves blaze forth the death of princes.

Julius Caesar, Act II, Scene II.

It is an ancient superstition that strange and rare celestial events such as comets, meteor showers, and supernovae are the accompaniment of important occasions for men on Earth. Universal education is slowly erasing this belief. Man now tries to see the Universe objectively, not as a backcloth for his own activities.

Perhaps, then, it will not be taken as a sign of the wrath of heaven if an exploding star puts out of action for a year or so our complex modern system of electrical communications—our favourite television programmes included.

Although they are part of our daily lives, these modern communication methods, especially radar and television, have existed for but a moment in man's history, which is itself almost vanishingly brief in terms of the age of the Earth. Electrical communications of all kinds have existed for too short a time for their interaction with many of the rarer kinds of celestial phenomena to be known.

It is not yet thirty years since the discovery of radio waves from outer space was made by Karl Jansky, and only twenty since they were first studied seriously on a large scale.

In 1932, Jansky's employers were quite contemptuous of his epoch-making work, and directed his efforts into other channels; scientists in general were just as short-sighted. It took a World War to get things moving.

One day early in 1942, the Early Warning Radar Chain in England was alerted by a barrage of radio noise of intense power. Many observers believed this to be radio jamming of a new kind, probably the prelude to some mass attack, and in research centres all over the country efforts were made to track down the interference; it lasted for two whole days, but the source was not traced.

Eventually, scientists who had been carefully studying the reports and records concluded that, beyond all doubt, the interference originated from the Sun. With the passing of a large sunspot, the interference vanished.

In 1944, cosmic radio noise again aroused government interest, when attempts to locate V.2 rockets by long-range radar were defeated by the radiation coming from the constellation of Sagittarius. By the time the war ended, radio astronomy was coming into its own, and since then the governments of countries all over the world have been allocating increasingly large sums to assist research in this field, the importance of which is still hard to assess.

It is now known that a significant part of the considerable radio energy which impinges upon the earth from outer space is due to emission from supernovae remnants, the violently expanding gaseous shells of long-since exploded stars. Since the last recorded supernova in our Galaxy was Kepler's Star, of 1604, and since supernova activity declines quite rapidly after the initial cataclysmic phase, the full impact of these titanic stellar explosions is quite unknown; but a few simple calculations show that the effects could be serious, even if the outburst occurred at hundreds of millions of times the distance of the Sun.

EXPLODING STARS

Novae are variable stars which differ from other types of variable star in that the outburst is non-recurrent, or occurs only at very long intervals. For reasons which are only now becoming understood by astrophysicists, a tremendous explosion occurs: within a few hours the brightness of the star increases by a factor of 10,000 or 100,000 (ten to twelve magnitudes), and simultaneously a gaseous shell is ejected with a velocity of the order of 1000 miles per second. This shell is at first opaque, and therefore of high emissivity, but as it continues to expand and become more tenuous it also becomes transparent, so that its emissivity drops to a low value, and the total luminosity therefore decreases, falling back over a period of some months to around the value which existed before the explosion.

The power output from a nova at the peak of the explosion, is of the order of 10^{31} watts, or about 100,000 times the power output of the Sun. Among the 10^{11} stars in our own Milky Way Galaxy, novae brighter than the ninth magnitude occur with a frequency of about 20 per annum, and well over a hundred have been observed.

Supernovae occur less often than novae, and although the observed phenomena are similar, the awesome explosion is of enormously greater violence. The peak power is of the order of 10^{34} watts for Type II Supernovae, and 10^{35} watts or more for Type I Supernovae, which is of the same order as the total power output from a galaxy of one hundred thousand million stars. The velocity with which the gaseous shell is expelled is usually of the order of 2000 to 3000 miles per second; so high that much of the ejected material escapes from the gravitational field of the core and continues to rush outwards indefinitely. A supernova observed in the great Andromeda galaxy, in 1885, had an absolute magnitude of $-15{\cdot}4$, so that it outshone the Sun by 20 magnitudes, or a factor of 100 million.

THE MECHANISM OF STELLAR EXPLOSIONS

Although both novae and supernovae are rare events by human time scales, they are the common lot of most stars, sooner or later. All stars which exceed in mass 1·44 times the mass of the sun (a parameter known as the Chandrasekhar Limit) must eventually explode, and slough off sufficient material to bring their mass within the fashionable boundary. It is clear that supernova explosions can only vary in power to a limited extent, since the explosion will be proportional to the mass of the star, but this is limited at the lower end of the scale by the Chandrasekhar Limit, and at the upper end by the observed fact that stars just do not have a mass of more than 95 solar masses. Few have a mass of more than 60 solar masses, since above this value they are "pulsationally unstable".

Astrophysicists consider the supernova explosion to be the result of the sudden collapse of a supergiant star which has exhausted its supplies of hydrogen and can no longer

TABLE I—SOME SUPERNOVAE IN HISTORY

Date Appearance	Duration Visible	Location	Notes on Identification	Events of Contemporary History
5 B.C.	More than 70 days	Near α Aqu.	Possibly a radio point source	4 B.C., true date of birth of Jesus of Nazareth. Augustus Caesar was Roman Emperor.
A.D. 185	7 months	Between α and β	Probably a radio point source	Marcus Aurelius died in 180.
A.D. 369 March	6 months		Radio point source. Baade and Minkowski photographed filamentary remnant	Theodosius recovered Valentia in 368.
A.D. 396 August	5 months	Taurus		Roman Legions left Britain five years later. Theodosius the Great died in 395.
A.D. 437 Feb. 26th		Gem.		Vandals took Carthage in 439.
A.D. 827		Sco.		Charlemagne, circa 800. Ecgbert became first king of England in 829.
A.D. 1006		Near $\varkappa$ Lupas		Ethelred the Unready, 978-1016. Danes ravaged the inland parts of Wessex, in 1006.
A.D. 1054 June 10th	More than 12 months	Near ζ Tau.	Crab Nebula Powerful radio point source	Edward the Confessor, 1042-1066. Siward defeated Macbeth in 1054.
A.D. 1181 Aug. 6th	185 days	Cas.		Henry II, 1154-1189. Assize of Arms, 1181.
A.D. 1203	10 days	Sco.		John, 1199-1216. Fourth Crusade, 1202. Oxford and Cambridge Universities founded circa 1200.
A.D. 1230	3 months	In south of 109 Her.		Henry III, 1216-1272. Frederick II launched Sixth Crusade in 1228.
A.D. 1572 Nov. 8th	18 months	Near γ Cas.	Tycho Brahe's star A strong radio source	Elizabeth I, 1558-1603. Galileo, 1564-1643. Francis Bacon, 1561-1626. Johann Kepler, 1571-1630.
A.D. 1604 Oct. 10th	1 year	Oph.	Radio point source and photographic remnant	James VI of Scotland and James I of England, 1603-1625. Hamlet published in 1603.

maintain its internal radiation pressure by means of the energy released from the fusion of hydrogen isotopes to form alpha particles. The star continues to radiate energy from its blue-hot surface, and therefore it shrinks under the pull of its own gravitational field.

Since the supergiant, like all stars, is rotating, the shrinkage means that it must spin faster so as to conserve angular momentum. As the spinning mass shrinks still further its temperature rises until the core attains some 4000 million degrees, when nuclear reactions which are strongly endothermic begin to take place. The central core now shrinks still more violently, and the rotational forces rise to enormous values, to maintain total momentum.

Although the mass of the star is probably between 10 and 60 solar masses, its radius shrinks to less than the radius of the Earth, so that its mean density becomes something like 92 million, or around 1200 tons/cu. in.; the density of the core may be as much as a million times greater. This super-dense mass is spinning at about one revolution per second, so that the peripheral velocity is of the order of 100 million m.p.h.

The surface temperature is now some millions of degrees, so that the peak of the radiated energy is shifted from the visible region, right through the ultraviolet and into the short *x*-ray part of the spectrum. Suddenly, in little more than a second, this incredible condensation of energy flies apart with unthinkable fury. The star does not disintegrate completely, however, and a dense superhot nucleus remains, which eventually cools down to a white dwarf star.

DATA ON PAST GALACTIC SUPERNOVAE

Recently the study of novae and supernovae has grown to considerable importance because of the information which astronomers and astrophysicists can deduce from their behaviour, and which throws a new light upon theories of stellar evolution and of cosmology. In the past, novae, like other rare celestial events, were regarded with

superstitious awe as portents and omens; had it not been for this misplaced respect, we would probably not have had the records which exist and which date back for about 2500 years.

Within the last five years the Academia Sinica, Peking, has made a complete survey of historical Chinese and Japanese documents (which go back much farther than any European records of astronomical events) and has published a new catalogue of 90 novae and supernovae observed up to the end of the 17th century. As a result of this exhaustive study the Academia Sinica came to two new conclusions: (1) that the frequency of occurrence of supernovae within the Milky Way system is about one every 150 years; (2) that novae are found to be noticeably concentrated in galactic latitude towards the galactic plane. Table 1 has been prepared from the data in the new Chinese Catalogue, together with additional material. In the section which follows, detailed information is given concerning some of the supernovae which have been identified with strong radio sources.

"RADIO STARS" AND EXPLODING STARS

The popular appellation "radio star" is a misnomer. The Sun is the only star that is observed to emit radio waves. The other localised sources of radio emission which have so far been discovered, and which now number about 3000, are all much larger objects; they vary from the remnants of galactic supernovae, a few light-years in diameter, to entire galaxies with diameters of tens of kiloparsecs.

By comparison with these other sources, the Sun is a very feeble radio emitter, although its relative nearness compensates for its lack of intrinsic radio brightness. The radiation intensity at the Earth's surface is measured in Flux Units; one unit equals 10^{-22} watts/sq. m./cycle/sec., at some specified wavelength or frequency.

The flux due to the quiet Sun is about 1·9 units on a wavelength of 3 metres, while at the same wavelength the source known as Cassiopeia A, the burnt-out shell of a sixteen-hundred-years-old supernova, gives 1·7 units. This is the most intense source known (ignoring the planet Jupiter, which emits irregular short bursts of more than 50 units), and its distance from the Earth is about 600 million times that of the Sun.

The second most intense radio source is that known as Cygnus A, the flux density at 3 metres wavelength from this source being 1·2 units. Cygnus A, however, is about 400 million light years away, or about 20 billion times as far as the Sun, and it is an object of impressive size, comprising two entire spiral galaxies, each of about 100,000 million stars, in collision at a velocity of about 40,000 km./s.

SOME RECORDED SUPERNOVA A.D. 369

Unfortunately, there is no detailed account available of the original outburst, since it occurred at a vast distance, and long before the invention of the telescope. The object which is now believed to be the ejected shell of the supernova is an extended gaseous nebulosity, very faintly illuminated, with great wisps and filaments of turbulent material in violent motion at thousands of miles per second. This nebula, of a previously unknown type, was discovered by Baade and Minkowski in 1954 as the result of a deliberate search with the 200-in. telescope at Palomar for an optical counterpart to the radio source 23NSA, discovered by Ryle and Smith in 1948. It is the most intense radio source known in the sky; it has an angular extent of about four minutes of arc, and an emission intensity at 100 Mc/s of 1·7 flux units.

A.D. 437

The Gemini radio source, 06N2A, has been identified with the galactic nebulosity IC433. A photograph of this object, taken with the 48-in. Schmidt camera at Palomar, shows that the nebula is roughly circular in shape and about 48 minutes of arc in diameter. The optically bright regions show a filamentary structure. The radio emission at 81·5 Mc/s is about 0·06 flux units. The filaments of the nebulosity show a turbulent motion, with velocities of the order of a few hundred km./s.

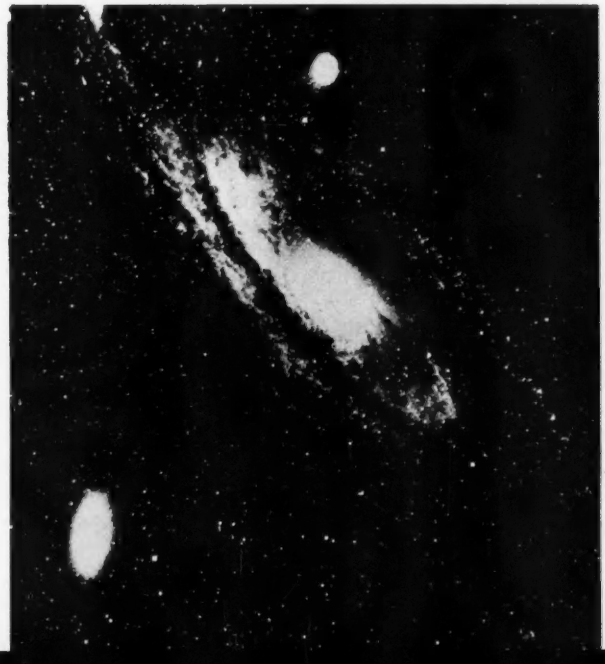
A.D. 1054

"In the first year of the period Chih-ho, the fifth moon, the day chi-chou, a guest star appeared several inches south-east of Tien-Kuan. After more than a year it gradually became invisible." This extract is from the "History of the Sung Dynasty".

The astronomer went on to show how smart he was by interpreting the event as a sign that the reigning Emperor was a very worthy man. From what is now known to be the distance (about one kiloparsec), and the statement that

THE GREAT NEBULA IN ANDROMEDA. *How our own Milky Way Galaxy would appear if viewed from a distance of 440 kiloparsecs (1,436,000 light-years). The Great Andromeda Nebula (M.31) is the nearest spiral galaxy to our own, and is very similar in structure. A number of novae and supernovae have been observed in this Great Nebula. Two other nebulae appear in the photograph, NGC 205 (the larger) and M.32 (the smaller). They are at approximately the same distance as the Great Nebula.*

(Photo: Yerkes Observatory)



CRAB NEBULA IN TAURUS—*this is an intense radio source.*
(Photo: California Institute of Technology)

at its maximum brightness the guest star was as bright as Venus, it may be calculated that at the peak of the explosion the absolute brightness was more than 100 million times that of the Sun.

In 1949, Bolton, Stanley and Slee suggested that the intense radio source, OSN2A, might be associated with the peculiar photographic object known as the Crab Nebula, and subsequent accurate measurements of the position of the source and of its angular measurements established the identity beyond doubt.

The present diameter of the nebula is about six light-years, and it is still expanding with a velocity of about 680 miles/sec. At the centre of the nebula two small stars are visible, one of which is thought to be the remnant of the original "guest star", and has been estimated to be still some 30,000 times brighter than the Sun.

Minkowski has calculated that the surface temperature of this remnant is about half a million degrees, and that its radius is only about 1/50th that of the Sun, so that its mean density is about 3 tons/cu. in. The temperature of the nebula itself has been calculated to be about 50,000°K., which is thousands of times too low for the observed flux density of 0·16 units (at 100 Mc/s) to be accounted for by thermal processes, and the mass of the nebula has been computed as about fifteen solar masses.

In 1954, the Soviet astronomer V. A. Dombrovsky established that the light from the Crab Nebula is polarised; later, T. Walraven of the Netherlands showed that the polarisation varies greatly in different parts of the nebula. In 1953, Shklovskii, and subsequently Dort and Walraven, developed theories to explain both the polarisation of the light and the unexpectedly high intensity of the radio emission, as a synchrotron mechanism resulting from the movement of very high energy electrons in a weak magnetic field.

A.D. 1572

The famous Danish astronomer Tycho Brahe is credited with reporting the supernova of November 8, 1572. Although three magnitudes less bright than the 1054 supernova (about 1/16th) it was still a striking object, outshining all the stars and all the planets except Venus. The identification of the radio source, Cassiopeia B, with Tycho Brahe's Star, was made by Hanbury Brown and Hazard in 1952. The intensity of the source at 100 Mc/s is 0·017 flux units.

A.D. 1604

The supernova of October 10, 1604 is associated with the name of Johann Kepler, the distinguished pupil of Tycho Brahe. The identification of the radio source in Ophiuchus with Kepler's Star was made by the Cambridge Radio Astronomy Group in 1955. The emission intensity of this source is 0·02 flux units at 100 Mc/s/sec. Detailed observations of the outburst have not been recorded, which is scarcely surprising since the magnitude at maximum (−2) was little brighter than Sirius, and the invention of the telescope by Galileo was still five years in the future.

THE FREQUENCY SPECTRUM OF GALACTIC NOISE

Very little reliable information is as yet available either as to the spectrum of galactic background radiation or of the point sources. Measurements of the frequency spectrum are difficult because the flux intensity is extremely feeble at the shorter wavelengths. The first measurements were made in 1946 by Moxon on wavelengths from 1·5 to 7·5 metres; he concluded that the intensity of noise in the galactic plane varied as $\lambda^{0.8}$, and as $\lambda^{0.1}$ away from the galactic plane.

In 1948, Herbstreit and Johler gave a figure of $\lambda^{2.41}$ without differentiating between the noise from different parts of the galaxy. More recent results by Australian astronomers, and by Hanbury Brown at Jodrell Bank, suggest that it is reasonable to conclude that the intensity of the noise from the direction of the galactic plane varies as $\lambda^{0.7}$. Measurements of the noise distribution from some of the more intense point sources have been made by Bolton and Slee over the frequency range 40 Mc/s to 160 Mc/s. For the sources in Cygnus and in Centaurus they find that the intensity varies as $\lambda^{1.0}$.

THE RADIO POWER FROM A CLOSE SUPERNOVA

Let us imagine that a new supernova explodes into view at a distance of about four light years from the Sun. This is the distance of the nearest known star, Proxima Centauri, and is therefore the worst possible case; it is a quite imaginary case, since the mass of Proxima Centauri is about 0·1 solar masses, and thus far below the Chandrasekhar Limit.

We may calculate the radiation intensity in two different ways, depending upon whether we assume a thermal or a non-thermal model for the source. It is, of course, known that the radiation at radio frequencies from supernovae must be generated by some kind of synchrotron mechanism,

since on a purely thermal basis improbable temperatures would be required—something of the order of 100 million million degrees Kelvin. Nevertheless, the thermal component must be taken into account, since it will be present whether or not enhanced radiation due to other processes is produced.

Taking the thermal model first, the solar radiation is $3{\cdot}86\times10^{26}$ watts, and the maximum output from a supernova is of the order of 1000 million times as great, that is, about 10^{35} watts. Minkowski has calculated that the nucleus of the Crab Nebula is a star with a radius 1/50th that of the Sun, or about $1{\cdot}4\times10^{9}$ cm. Its surface area is therefore about $2{\cdot}46\times10^{19}$ cm.^{2}. At peak output, the radiation density was therefore:

$$10^{35}/2{\cdot}46\times10^{19}=4{\cdot}06\times10^{15}\ \text{watt/cm.}^2 \qquad (1)$$

Dividing by the Stefan-Boltzmann constant, we have:

$$4{\cdot}06\times10^{15}/5{\cdot}67\times10^{-12}=7{\cdot}17\times10^{26}\ ^\circ\text{K}^4 \qquad (2)$$

Taking the fourth root, we obtain for the temperature of the star at maximum:

$$(7{\cdot}17\times10^{26})^{0.25}=5{\cdot}1\times10^{6}\ ^\circ\text{K} \qquad (3)$$

Considering the star as a blackbody radiator, the appropriate formula for the power emitted at a wavelength λ (metres) in the frequency interval Δf is:

$$P=\frac{2\pi kT}{\lambda^2}\Delta f\ \text{watt/metre}^2 \qquad (4)$$

If the radius of the star is r the blackbody emission from the entire surface is:

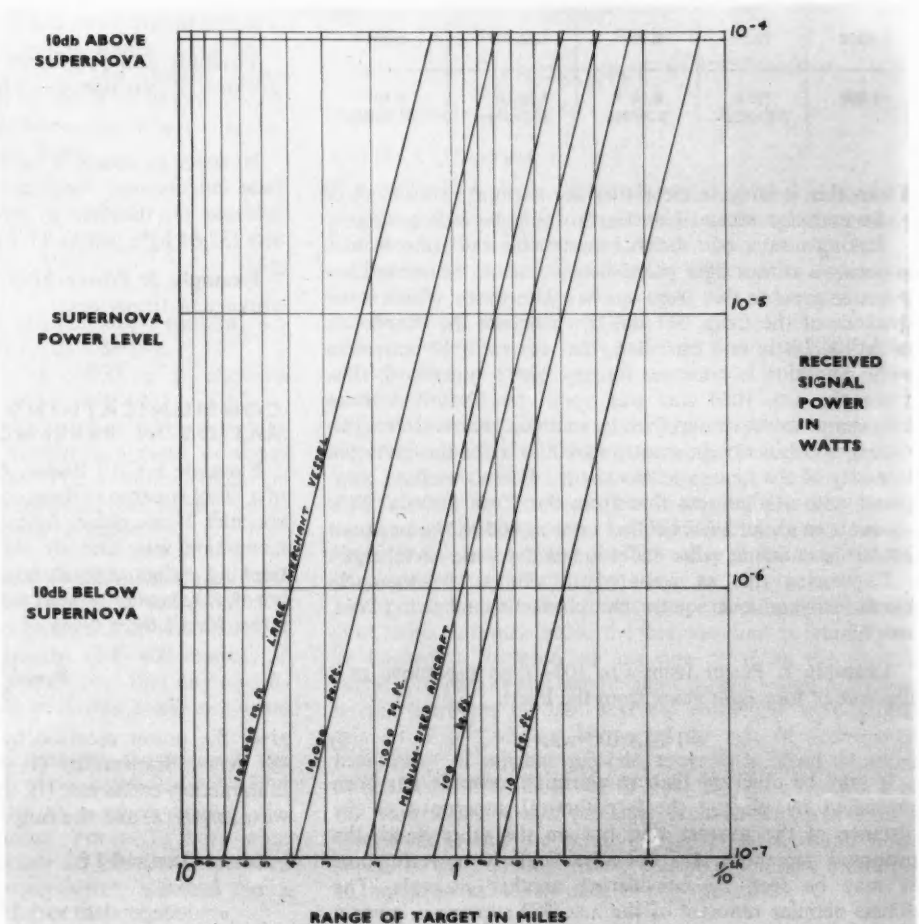
$$P_t=\frac{2\pi kT}{\lambda^2}\Delta f.4\pi r^2\ \text{watts} \qquad (5)$$

Thus, if R is the Earth-star distance (or Sun-star distance, which is virtually the same) the amount received on the Earth will be:

$$P_e=\frac{2\pi kT}{\lambda^2}\Delta f.\left(\frac{r}{R}\right)^2\ \text{watt/metre}^2 \qquad (6)$$

If we consider a wavelength of one metre, and take T as five million degrees, we then have:

$$P_e=2\pi\times1{\cdot}38\times10^{-23}\times5\times10^{6}\times\left(\frac{1{\cdot}4\times10^{9}}{4000\times1{\cdot}496\times10^{13}}\right)^2$$
$$=2{\cdot}4\times10^{-31}\ \text{watt/metre}^2/\text{c/s}$$
$$=2{\cdot}4\times10^{-9}\ \text{flux units} \qquad (7)$$



Effective range of 60 kW, 3 cm. Radar for various targets in presence of a Supernova

TABLE 2—CIVIL RADAR

Range in feet

Along the top of Tables 2 and 3 is shown range in feet, down the side is aerial area in ft.²

	5000	10,000	25,000	50,000	100,000
10 ft²	$2.3.10^{-8}$	$1.44.10^{-9}$	$3.69.10^{-11}$	$2.3.10^{-12}$	$1.44.10^{-13}$
100 ft²	$2.3.10^{-7}$	$1.44.10^{-8}$	$3.69.10^{-10}$	$2.3.10^{-11}$	$1.44.10^{-12}$
1000 ft²	$2.3.10^{-6}$	$1.44.10^{-7}$	$3.69.10^{-9}$	$2.3.10^{-10}$	$1.44.10^{-11}$
10,000 ft²	$2.3.10^{-5}$ 1 mile	$1.44.10^{-6}$ 2 miles	$3.69.10^{-8}$ 5 miles	$2.3.10^{-9}$ 10 miles	$1.44.10^{-10}$ 20 miles

TABLE 3—DISTANT EARLY WARNING RADAR

Range in feet

	5000	10,000	50,000	100,000
100	1.279	8.10^{-2}	$1.28.10^{-4}$	8.10^{-6}
1000	12.79	8.10^{-1}	$1.28.10^{-3}$	8.10^{-5}
10,000	127.9 1 mile	8.10^{0} 2 miles	$1.28.10^{-2}$ 10 miles	8.10^{-4} 20 miles

From this it is quite clear that the thermal component of radio emission received on Earth would be indetectable.

Taking now a non-thermal model, the radiation from a supernova at four light years distance would be one million times as great as that from one at a kiloparsec, which is the distance of the Crab Nebula. If we accept the conclusion of Mills, Little and Sheridan, that the ratio of optical to radio emission is constant for any given supernova, then since the A.D. 1054 star was about ten thousand times brighter at its maximum than its remnant is now (10 magnitudes), we thus obtain a ratio of 10^{10} : 1 for the radiation intensity of the new supernova at the Earth's surface, compared with the present flux from the Crab Nebula. This amounts to about $1{\cdot}6\times10^{9}$ flux units at 100 Mc/s, or about 8×10^{8} as much as solar radiation at the same wavelength.

Expressing this as watts/metre² for a 10 megacycle bandwidth and one square metre effective receiving area, we obtain:

Example 1. Power from A.D. 1054 type supernova at a distance of four light years from the Earth

$$=1{\cdot}74\times10^{-6}\text{ watt} \qquad (8)$$

It may be objected that an alarming example has been presented by placing the hypothetical supernova at the distance of the nearest star, but on the other hand, the proposed supernova was not a particularly powerful one, as may be seen by considering another example. The diffuse nebular remnant of the A.D. 369 supernova gives a flux intensity at the Earth's surface more than ten times that from the Crab Nebula, and its estimated distance is about 2½ times as great; its absolute intensity must therefore be about 65 times greater. There is insufficient evidence from which to derive an accurate figure for the amount by which the intensity of the radiation from this source has declined in nearly 1600 years, but a reasonable estimate would be about 10^{5}, or 12·5 magnitudes. On this basis, a supernova at a distance of four light years could give $650\times1{\cdot}6\times10^{9}=1{\cdot}03\times10^{12}$ flux units. Expressing this new figure as watts/metre² for a 10 megacycle bandwidth and one square metre receiving area, we obtain:

Example 2. Power from A.D. 369 type supernova at a distance of four light years from the Earth

$$=1{\cdot}12\times10^{-3}\text{ watt} \qquad (9)$$

In order to obtain a "standard" supernova on which to base calculations, we may take the second example and increase the distance to the more likely value of 10 parsecs (32·64 light years). This gives:

Example 3. Power from A.D. 369 type supernova at a distance of 10 parsecs.

$$=1{\cdot}68\times10^{-5}\text{ watt/metre}^2\text{/10 Mc/s} \qquad (10)$$

COMMUNICATIONS SIGNAL/NOISE RATIOS IN PRESENCE OF A SUPERNOVA

Example 1. Civil Radar. As a first example of the impact of a close supernova upon communications systems we may consider 3 cm. radar, such as is used for standard marine navigation sets, aircraft cloud warning sets, and aircraft tracking radars used in relation to Air Traffic Control. A set of values may be selected which is reasonably representative for all three types of radar. The basic radar equation

$$P_r=\frac{Pt\,\sigma\,A^2\,f^2}{4\,\pi\,R^4\,\lambda^2} \qquad (11)$$

gives the power received by a radar receiver in terms of the power transmitted (P_t), the aerial aperture (A), the illumination coefficient (f), the effective target area (σ), the wavelength (λ) and the range (R).

Let λ=3cm.=0·1 ft.
f=0·6
σ=independent variable
P_t=60 kilowatts

Let A = 10 square feet
R = independent variable

$$\text{Then } P_r = \frac{6\times10^4\times10^2\times0{\cdot}6^2}{4\pi\times0{\cdot}01}\times\frac{\sigma}{R^4}$$

$$= 1{\cdot}44\times10^6\times\frac{\sigma}{R^4}\text{ watts} \qquad (12)$$

Inserting some values for the two independent variables we obtain Table 2. More extensive results are given in Graph 1 (page 361).

Since the aerial is of $0{\cdot}6\times10=6$ sq. ft. effective area, $=0{\cdot}56$ metre^2, supernova power will be $1{\cdot}68\times10^{-5}\times0{\cdot}56=9{\cdot}4\times10^{-6}$ watts. The bandwidth of 10 megacycles should be quite suitable for the radar case.

For a medium-sized merchant vessel, the echoing area is about 86,000 sq. ft., so that the signal-to-noise ratio will be unity at a range of about two miles. For a medium-sized passenger aircraft, the echoing area is about 430 sq. ft., so that the signal-to-noise ratio will be unity at a range of about one mile. Such radars are clearly quite unable to perform their proper function under these conditions. Even when the supernova is not in the main beam, it can still seriously interfere through the sidelobes.

Example 2. Distant Early Warning Radar. Consider a fairly powerful early warning array; the antenna might measure, say, 100 ft. in length by 50 ft. in height, giving an aperture of 5000 sq. ft. Peak power might be 100 megawatts, at a wavelength of 100 cm. Then:

$$Pr = \frac{10^8\times2{\cdot}5\times10^7\times0{\cdot}6^2}{4\pi\times3^2}\times\frac{\sigma}{R^4}$$

$$= 8\times10^{12}\times\frac{\sigma}{R^4} \qquad (13)$$

Inserting values for the two independent variables, we obtain Table 3.

Since the aerial is of $5000\times0{\cdot}6=3000$ sq. ft. effective area $=280$ metres^2, supernova power will be $1{\cdot}68\times10^{-5}\times280=4{\cdot}7\times10^{-3}$ watts at the receiver. For unity signal-to-noise ratio the E.W. radar is limited to a range of about ten miles, which is utterly useless. The conditions might be considerably worse than as shown, since at longer wavelength the synchrotron noise would be larger.

Example 3. Short-Wave Radio Communication. A non-directional broadcasting station, having a power of 100 kilowatts at a wavelength of 6 metres, will serve as a useful example. At the longer wavelengths (200–400 metres) of most long-range stations it is improbable that any significant quantity of extraterrestrial radiation could penetrate the ionosphere.

Apart from wavelength considerations, the power of the interference will also depend upon bandwidth, so that television transmissions will be at a much greater disadvantage than sound broadcasts. For a 10 kc/s wide sound channel, Equation 10 gives an effective supernova noise power of $1{\cdot}68\times10^{-8}$ watt/metre^2, whereas for a 2 Mc/s wide video channel the power is $3{\cdot}36\times10^{-6}$ watt/metre^2.

Example 4. Sound Broadcasting. Assuming the power from the broadcast station, P_b, to be distributed uniformly over a hemisphere, the intensity, P_r, at any distance, d, from the transmitter will be given by:

$$P_r = P_b/2\pi d^2 \qquad (14)$$

The intensity will be ten times the intensity of the supernova interference (signal-to-noise ratio of 10 db) when

$$d^2 = \frac{10^5}{2\pi\times1{\cdot}68\times10^{-7}} = 9{\cdot}5\times10^{10}$$

whence $d = 3{\cdot}08\times10^5$ metres $= 191{\cdot}5$ miles. (15)

It is apparent that the normal service range of the station would not be seriously interfered with by this level of noise. Had the supernova been placed at the originally suggested distance of four light years the result would be much more serious; the range for 10 db signal/noise ratio works out at about 7·4 miles.

Example 5. Television Broadcasting. Making the appropriate change from 10 Mc/s to 2 Mc/s bandwidth alters equation (15) to give instead:

$$d^2 = \frac{10^5}{2\pi\times3{\cdot}36\times10^{-3}} = 4{\cdot}78\times10^6 \text{ metres}$$

from which $d = 2{\cdot}186\times10^{-3}$ metres $= 1{\cdot}36$ miles (16)

CONCLUSIONS

A new supernova, a real "radio star", arising in the solar neighbourhood could have disastrous, though temporary and intermittent, effects upon electrical communications.

Broadcasting services would be affected to a more or less severe extent depending upon the wavelength and bandwidth of the transmission. In general, sound transmission would not be badly affected except at very short wavelengths, but television transmissions could be completely obliterated.

Civil radar installations of the types used for navigation, air traffic control, and storm warning, could become useless, as also could the giant military early warning radars, despite their enormous power. Some of the very latest communications systems (tropospheric forward scatter links; the Janet system; satellite relay links) could suffer the same fate as radar.

The interference would, of course, occur only when the new radio star was above the horizon, and it would thus be limited in duration, at any one point on the Earth's surface, to part of the day or night. Local communications would therefore be less severely disturbed than global systems. From what is known of the rate of decrease of luminosity of ancient galactic supernovae (and of more recent supernovae observed in other galaxies), the worst of the interference would probably not last for more than a few months, but the general level of background noise would be permanently raised, thus setting a new limitation to the useful sensitivity of receiving apparatus.

THE PROGRESS OF SCIENCE

(continued from page 324)

PLANT INDEX BY COMPUTER

Automatic compilation is being used to publish a master index and catalogue of 1,700,000 plants of the earth identified by man. Details of the International Plant Index (IPI) were announced this summer at a gathering of taxonomists (plant classifiers) at the Botanical Institute of Genoa University.

The completed index of the earth's plant life will run to fifty volumes and be the key reference catalogue for botanical researchers all over the world. It is intended to eliminate the confusion that has developed over the decades in plant identification through scientists working in widely separated places giving different names and classifications to the same plant.

It is estimated that to complete such an ambitious catalogue of existing plant publications alone, would have taken fifty people ten years without the help of data-processing equipment. IBM data analysis equipment is being used to code the mass of information on to punched cards which are then fed to the Yale University IBM 407 machine for printing out. So far 50,000 cards have been completed and the total project, employing seven people only, is expected to be finished in five years. Then it is hoped to keep it up to date by establishing five sub-centres in different parts of the world.

MET. OFFICE TAKES UP ROCKETRY

The Meteorological Office is to start launching rockets on a considerable scale next year to fill out the weather picture at the heights now required for the safe operation of high-flying jet aircraft. The first launchings will take place probably in the spring of 1962 from either the rocket range in the Hebrides or that at Aberporth on Cardigan Bay.

During the first year of operations the rockets will be fired at the rate of one a week. Later it is expected that a hundred a year will be launched, and the intention is to extend the number of launching sites so as to keep a wider area of the upper weather under surveillance.

LETTERS TO THE EDITOR

Sir:

I was surprised to learn recently that some diamonds have atoms of Nitrogen incorporated in their molecules. The article "New Research Tools for the Archaeologist" (June) has prompted me to ask whether this Nitrogen was originally radioactive Carbon and if so whether it has been used to date the diamond-bearing rocks? I found the whole of this article most interesting.

Yours faithfully,

(MRS) E. M. WENTWORTH

194 Coombe Lane, S.W.20

Dr M. J. Aitken, the author, writes:

Nitrogen is one of several impurities found in diamonds, and its origin has not yet been investigated. However, in most diamonds it is present to about 0·1%, and I think this rules out the possibility that it was derived from radioactive carbon. The ratio of radioactive carbon (C14) to ordinary carbon (C12) is only one part in a million million in living organic matter.

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THE BOOKSHELF

Protection Against Radiation

By J. D. Abbatt, J. R. A. Lakey and D. J. Mathias (*London, Cassell and Co. Ltd, 1961, 235 pp., 25s.*)

Radiation protection is, as yet, poorly served with text-books, though the subject has so many facets that any one book can only attempt either to select a single aspect, or skim the surface of several. This is only the second book of the more general type to appear in Great Britain, and is a considerable improvement on the previous work, having a better balance, possibly because Dr Abbatt has brought the medical side into its proper perspective, without belittling the work of the physicist; in the chapter on medical care of radiation workers, he states clearly that the "health physicist and the medical practitioner should work together as equal professional colleagues and not on a doctor/technician basis".

The earlier chapters, covering biological effects of radiation, physics, natural background, sources of radiation and medical care of workers, all give a good general background and there are two good chapters on personnel protection and working conditions.

The sections on dosimetry and detection, and on maximum permissible levels would, however, have gained considerably by somewhat different treatment. The former gives the impression of being a catalogue of methods and instruments, with a brief amplification of each heading, and would probably have been improved by an even more general treatment.

In the Introduction, the authors state that maximum permissible levels (for internal radiation) have not been included in a table of radioisotopes since they are continually under review and may easily be obtained from the Recommendations of the International Commission on Radiological Protection. This is undoubtedly the correct attitude, but the chapter on maximum permissible levels is inconsistent with this outlook since it contains very little more than a direct reprinting of part of the Report of the Main Commission of the ICRP. What is required here is an outline of the methods used in deriving maximum permissible levels.

There is a further inconsistency in the table of the so-called "K constant", described as the gamma dose-rate, in rontgens/hours, from 1 curie at 1 metre. As defined by Mayneord, the K factor is the dose-rate from 1 millicurie at 1 cm., which is ten times the figure given, so the same terminology should not be applied. There is, incidentally, a discrepancy of about 5% between the values in this table, compared with the normally accepted values, while the figure for A_s^{76} (0·23) differs considerably from the more usual 0·33.

Despite these criticisms, the book is a worthwhile addition to the literature, forming as it does, the best basic text-book on the subject yet available.

H. D. EVANS

Science Since Babylon

By Derek J. de Solla Price (*Yale University Press, $4·50*)

A piece of earnest and methodical scholarship such as one would expect from a young American historian of science, "Science Since Babylon" sets out to trace the origins and direction from earliest times to the present. It concludes that notwithstanding the phenomenal advances made in recent years, we stand at a crucial stage as we face the future of science.

Mr Price's historical knowledge is clearly great, if somewhat undigested; he relies more in telling his story on the relentless accumulation of facts than upon revealing the spirit of the great scientific revolutions with the single telling phrase, the illuminating interpretation. The glories of Greek mathematical argument and Chinese inventiveness and Babylonian astronomy occupy the first half of the book and provide a good deal of fascinating material. But then there follows a yawning gap, which includes almost all of the European Renaissance (Galileo and Da Vinci are scarcely mentioned), and we find ourselves in the nineteenth century, the evolution of scientific *technology* and the solid work of Maxwell, Roentgen and Huxley.

In his next chapter, the Diseases of Science, Mr Price dwells with considerable concern on the overriding problem that has faced the scientist of this century—namely, the fragmentation of disciplines until each seems to be working in a world of its own, cut off from all its neighbours; and the proliferation of scientific information published in the world's journals. (From 100 journals published at the beginning of the nineteenth century, the number has grown to almost 100,000, including some 300 journals of abstracts and several which abstract the abstracts.)

This bewildering compartmentalisation of science, as Mr Price sees it, leads to an even graver danger—the danger that young scientists, instead of being able to base their work on a foundation of the history and philosophy of science, the "humanism of science", are obliged to pick a subject and stay with it throughout their careers. Such an approach, akin to a blindfolded horse circling a water wheel, cannot result in the kind of breadth of vision that frees the scientist from mere drudgery; rather, it yokes him to being a technician for ever ploughing his isolated acre.

Einstein once said, with reference to motivation of scientific research: "You can't scratch if you don't itch". Mr Price adds, quite rightly, that if we don't reorient our methods of scientific education, our young scientists may altogether lose the itch to explore, and replace it merely with the itch to publish unreadable, irrelevant pedantry for the world's archives.

The Sounds of Language!

An Inquiry into the Role of Genetic Factors in the Development of Sound Systems

By L. F. Brosnahan (*Heffer, Cambridge, 250 pp., 25s.*)

The main theme—and origin—of this book is C. D. Darlington's (1947–1955) hypothesis of a genetical component of language. This postulates that human communities have certain preferences for

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specific articulations, for example, the "th" sound, and that these preferences are to an important extent determined by genetical differences.

This hypothesis has been severely criticised, for example, by Hogben and Mr Brosnahan admits that it is "perhaps rather sweeping and obviously intended to be provocative of further inquiry . . ." but he does his best to support it. In this he appears to the reviewer not very convincing.

As a linguist the author may perhaps be excused if he does not consistently distinguish between two entirely different propositions namely (1) that language in common with any other manifestation of life results from complex interactions of hereditary and environmental factors and (2) that it has been demonstrated that specific differences in sound production of certain populations are caused by specific demonstrable differences in the speech organs of the members of these groups

With the first proposition most people would agree, the second seems entirely unproven. As a geneticist the reviewer is not qualified to pronounce on the linguistic basis of the author's considerations; but even if this is accepted no genetical hypothesis emerges from a geographical distribution of pronunciation and its correlation with blood groups or other factors. No such conclusions are as a rule drawn from the well-known local parallelism of the number of storks and the birth rate.

In a descriptive way, though, Mr Brosnahan has some interesting and sound things to say and the book may serve some purpose by drawing the attention of biologists to the fascinating if obscure phenomenon of the development and change of certain aspects of language.

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Spiders, Men and Scorpions

By Theodore H. Savory (*University of London Press, 30s.*)

Many may consider the study of spiders and scorpions a dull subject, but to those who have a consuming interest in this branch of zoology—Arachnology—Mr Savory's book will be both stimulating and informative. And although to some this book may read somewhat like a museum catalogue for others it will fill the gap; for, surprising though it may appear, no one has hitherto been brave enough to write a history of the science of Arachnology. It is a chronicle of those men and women interested or passionate about arachnids, rather than about the spiders themselves. It records and correlates the names, dates, writings, and contributions of the arachnologists of every country since the days of early Greek civilisation, and it is well illustrated by photographs.

Aristotle has often been described as the founder of modern scientific method; not only was he the first to attempt a classification of the animals, but during his thirty years at Athens he wrote over twenty books on what we call biology. In one of his best-known works there are nearly fifty references to the creatures we now know as arachnids. As the reader may guess, the arachnids were named after a woman—"Arachne, daughter of Idmon, of Colophon, dweller in the tiny village of Hypaepa, renowned throughout Lydia for her skill in weaving. The very nymphs of the countryside would come to watch her spinning with easeful grace the wool that her father had dyed. . . ." In chapter two Mr Savory describes how Pallas, angered by the web in which Arachne had woven legends depicting scenes of the betrayal and seduction of women, turned her into a spider—her lovely body distorted and doomed to spin for ever.

The book traces, in chronological order, the authors who referred to arachnid insects in their writings; after Aristotle came Nicander, a century later, and then others—Diodor of Sicily and Pliny; after the Dark Ages, during the Middle Ages, the outstanding feature of Arachnology was "the belief in the formidable venom of the tarantula"; tarantism was the name given to the effects following the bite of the tarantula spider, and the belief that even harmless spiders can cause these dread symptoms persisted, surprisingly, right up to the nineteenth century.

In the nineteenth century arachnology came to be recognised as a special branch of entomology; Mr Savory describes the development of the science and the people who contributed to its progress, step by step. For those not deeply interested in the details the first part of the book will be more compelling since it describes how a science originated.

In answer to the question of why men should devote their time and energy to the study of spiders and their associates, there is a quotation from E. C. Large: "many worked to quench a curiosity. Some eyed mundane rewards, others eternal fame. Not a few found in the laboratory an escape from their wives or from the anxieties of stupid wars, or from the tedium of their ways of earning a living."

Ciba Foundation Symposium on "Quinones in Electron Transport"

Edited by G. E. W. Wolstenholme and C. M. O'Connor (*Churchill, 453 pp., 60s.*)

Few aspects of biochemical research are more fascinating than the growth of chance observations into major discoveries. In the case of the quinones which form the subject of this book, fortuitous observations of ultra-violet light absorption spectra led two independent groups, one at the Biochemistry Department of the University of Liverpool and the other at the Enzyme Institute of the University of Wisconsin, to isolate a new group of substances now known as the ubiquinones (coenzyme Q). The widespread occurrence of the ubiquinones and the closely related plastoquinone, as well as of vitamin K, and the evidence for their function in the electron transport system of living cells clearly indicate their importance. When one considers that much of this was published only in the last five years or so (the structure of ubiquinones, for example, was announced as recently as 1958), the rapid development of this new field is apparent. As usual, the Ciba Foundation is to be congratulated on organising one of their colloquia at the right time, whilst interest in the topic is still increasing, and on the publication of both the original contributions and the discussions which

form such valuable part of the colloquia.

The historical background of the researches culminating in the isolation of ubiquinone was vividly described at the meeting by Prof. R. A. Morton and Dr F. L. Crane and their contributions are recorded in the first two chapters. Full accounts of the synthesis of ubiquinone and of the chemistry of this quinone and of related compounds are given by Dr O. Isler, Dr K. Folkers and their colleagues in the two following papers.

The transfer of electrons from succinate or diphosphopyridine nucleotide to molecular oxygen by mitochondria is discussed in detail by Prof. D. E. Green, who places ubiquinone between the flavoproteins and cytochrome c_1 on an alternative path to cytochrome b in the electron transport chain. In the subsequent paper, Prof. E. C. Slater and his colleagues agree with this general conclusion.

The mechanism of oxidative phosphorylation is still largely conjectural despite much active research in recent years, and the possible function of quinones was considered in three papers. In a stimulating contribution, Dr V. M. Clark and Sir Alexander Todd discuss possible chemical mechanisms of phosphorylation by oxidation of quinol phosphates. They conclude that metaphosphate is generated as a transient intermediate which reacts with alcohols to form phosphate esters or with phosphates to form pyrophosphates. The relation of this reaction to oxidative phosphorylation in the respiratory chain is outlined with special reference to the oxidation-reduction of ubiquinone, but, as was pointed out in the discussion by Sir Hans Krebs, this scheme could account for only one phosphorylation of the three known to occur in the course of the transport of one electron pair.

Another major aspect of the biochemistry of these quinones which was discussed fully at the meeting is their biosynthesis. This work is clearly only beginning, but Prof. A. J. Birch gave an interesting summary of relevant biosynthetic pathways and two papers by Prof. R. E. Olson, Dr O. Wiss and their colleagues reported results on the biosynthesis of ubiquinone in animals. The isoprenoid side-chain of the molecule appears to be derived, as would be expected, from mevalonic acid, but the origin of the quinone ring structure is still obscure.

This summary, though far from complete, must suffice to give an indication of the scope of this book, but it should be stated that all the other contributions are also of the highest standard. The record of this Ciba colloquium will, therefore, be of great value.

H. R. V. ARNSTEIN
Medical Research Council

Seeing the Earth from Space

By Irving Adler (*London, Dennis Dobson, 12s. 6d.*)

The outstanding merit of this small book is that it is right up to date. It even includes, in the last chapter, a brief reference to Major Gagarin's and Commander Shepard's historic flights. Its other commendable features are the diagrams (drawn by Ruth Adler) which are simple and clear, and the good, relevant photographs.

To those already familiar with the basic principles of rockets and space flight, the book will add nothing new. However, although primarily intended for children, Mr Adler's book may well prove both interesting and informative to the intelligent layman; it is written in a clear, concise style. A sense of the poetic and more imaginative aspects of Man's exploration of Space are missing entirely, and therefore the dramatic and exciting side of Space travel must come from the reader.

The book sets down in a clear, easily understood form, details of the new satellites and "moons" that have been launched by the Russians and Americans. In the first chapter the historical development of rockets is followed by a clear explanation of how a rocket works. Our planet and its forces, and the factors of gravity, atmosphere and radiations surrounding it are also explained. Special attention is given to the Van Allen belts—belts of high energy particles, surrounding the Earth like a huge tyre, which emit radiations that are dangerous to life.

These particles were predicted to exist long before their actual discovery by a Norwegian scientist, Carl Stormer. He deduced that the particles are trapped by the Earth's magnetic field in a large ring around the Earth, about twenty thousand miles from its centre. The Earth satellites and moons recently put into orbit, have transmitted back information proving Stormer's predictions to be correct.

There are two of these Van Allen rings and they will have to be taken into account when plans are made for interplanetary flight; the amount of radiation on passing through them would be lethal. Space ships will have to be built with an effective shield; or they will have to take off from a suitable position, such as the poles, which would enable them to pass through the hole of the tyre, rather than across it.

R.E.

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THE EARTH, THE PLANETS AND THE STARS

By K. E. EDGEWORTH

D.S.O., M.C., F.R.A.S., M.I.E.E.

In this critical review of the theories of planetary and stellar evolution, the argument is developed in such a way that it should appeal to the professional astronomer; but the book is written in simple and straightforward language so that it can be readily understood by the ordinary reader. Mathematics in the text have been kept to a minimum, thus facilitating the task of the beginner, whilst the mathematically minded reader will find most of what he wants in the very full Appendix. *Illustrated. 25s.*

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SOCIETIES

FORTHCOMING MEETINGS

Sept. 1: Symposium on "Man In Space" at Royal Society of Arts, 6.30 p.m.
Oct. 2–6: 12th Congress of the International Astronautical Federation, Washington, D.C.
Oct. 7: Possible Forms of Extra-Terrestrial Life, by Dr Holmes-Siedle, 6.30 p.m.
Nov. 22: One-day Symposium on "Materials in Aerospace Technology", 10 a.m.–5 p.m.

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THE BOOKSHELF

Continued from page 367

The Skills of Interviewing

By Elizabeth Sidney and Margaret Brown (*Tavistock, 35s.*)

With the publication of this detailed, technical and far-ranging analysis of selecting the right man for the right job, it is at last clear that the bad old days are gone for ever. The time when an employer summed up a prospective employee by instinct, by his subjective reaction to the other man's personality, is irretrievably past—happily so, the authors keep reminding us in the course of 400 pages.

In place of the *ad hoc* approach practised by the old-fashioned boss, we now have a cool, dispassionate and sober-minded science known as employee selection which claims to extract relevant truths from among the nervous candidate's cloud of self-condemning irrelevancies. Compounded of sociology and the sensible point of view, the skills of interviewing appear to be able to penetrate to the very bottom of the interviewee's soul for signs of suitability.

Indeed, how could it fail to work? For, as Mrs Sidney and Mrs Brown point out, "The competent interviewer appears as a person of well above normal intelligence, in good health and has some experience of life. He is emotionally mature, calm, and persistent."

How many of us have not sat across a desk from such a monster of detached complacency, trembling lest some human failing be revealed to dash all our hopes for the job? And what if the candidate happens *not*-to-get-on-with-people; has a tic or is Jewish; an unorthodox private life or radical political views?

The chapter on "The Problem of Bias" does not reassure us that the candidate's professional competence will outweigh such "social maladjustments". For, no matter how well a man may do the job in question, he must also be a good mixer, bland in his views, conventional in behaviour, dress, and "facial adornment". (God help the man who wears a beard!)

There is altogether too much unrealistic sweetness and light in this book. With the exception of a late chapter on the essential tension and hostility intrinsic in the master-slave relationship (an example is given, in dialogue form, of a disagreement over Christmas leave between a wretched clerk and an inhuman personnel officer), we are left with the impression that industry runs not so much according to the laws of self-interest and ambition, as by brotherly love.

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PURE MAGNESIA 98%

* *Registered Trade Mark*

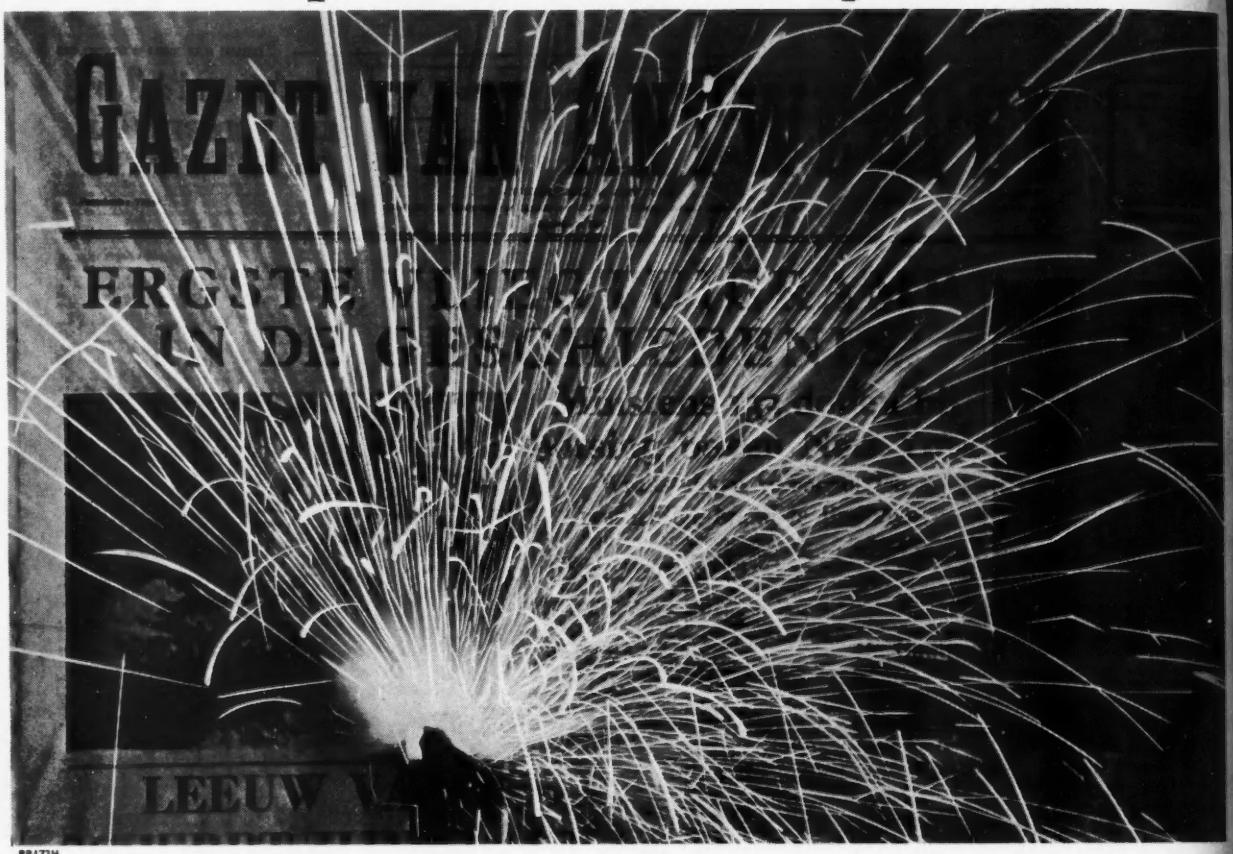
MORGAN REFRACTORIES LIMITED,
NESTON, WIRRAL, CHESHIRE.
TEL: NESTON 1406

Purox is the name of a new range of high purity Alumina, Magnesia and Zirconia refractories. These refractories contain no glassy bond and the Alumina is impervious. They are hard, strong, and have extremely high softening points. New techniques developed at Neston allow of the manufacture of complex shapes to close tolerances, and of single parts of considerable size. These materials open up entirely new possibilities in many fields.

MORGAN Refractories Ltd

NE 157A

Flemish as spoken in Wolverhampton



PR172H

Lit by the spluttering, steely-blue flames of welding arcs, the intricate cooling system of a nuclear reactor takes shape in Northern Belgium. For the 11,000th time, in the darkened inspection booth of a factory in the English Midlands, an X-ray negative is presented for close scrutiny, a head bends over it, and a hand writes a curt 'O.K.'

Sixty tons of gleaming aluminium are the link between the Belgian Atom Town at Mol and the English factory at Wolverhampton operated by I.C.I.—Britain's leading chemical company and an expert fabricator of non-ferrous metals. For the nuclear reactor BR2 at Mol, the cooling water needs to be contained in a labyrinth of aluminium pipes, made with perfect precision and faultlessly welded. I.C.I.—no mean contributor to Britain's nuclear projects—undertook the job, confirming the perfection of their work with 11,000 X-rays and sending a special team of welders to install the pipework at Mol.

When it's a question of making special assemblies in conventional metals, or supplying special metals such as zirconium, hafnium and beryllium for nuclear engineering projects, I.C.I. speaks a language that is well understood everywhere.

The influence of I.C.I. research and production is felt today in every corner of the globe

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